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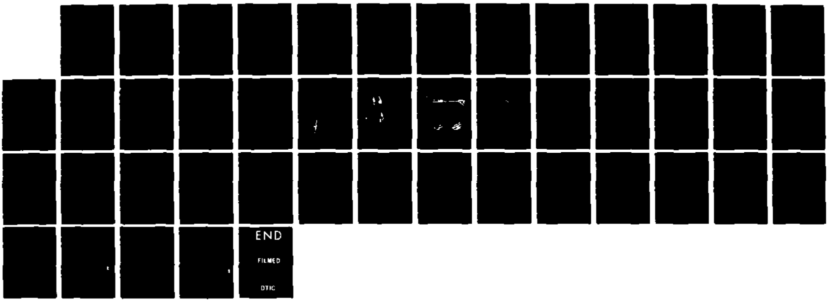

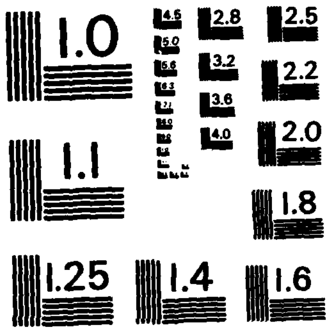

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TITLE: ASSESSMENT OF CROSS-BERTH CIRCULATION AT CHARLESTON NAVAL STATION

AUTHOR: J. A. Bailard, S. Jenkins, and F. Dellaripa

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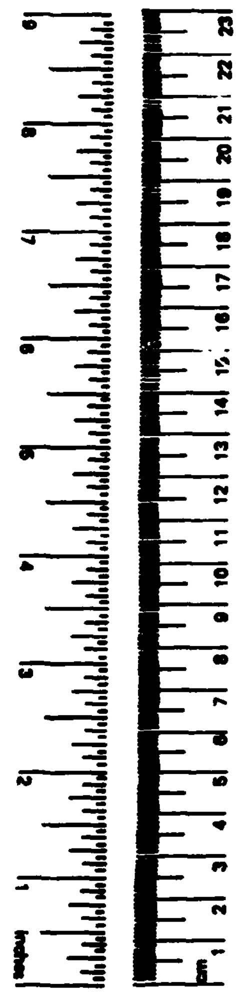
NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

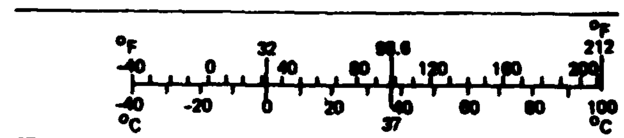
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Cross-berth circulation and discrete water properties were monitored during a 2-day period at Charleston Naval Station. The resulting measurements were used to evaluate the suitability of using scour jet arrays or barrier curtains to reduce the rate of sedimentation in berthing areas at the Naval Station. The results of the evaluation show that both scour jet arrays and barrier curtains may be viable methods for reducing siltation in the berthing areas. However, additional study of these technologies is recommended; in particular,

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Cross-berth circulation and discrete water properties were monitored during a 2-day period at Charleston Naval Station. The resulting measurements were used to evaluate the suitability of using scour jet arrays or barrier curtains to reduce the rate of sedimentation in berthing areas at the Naval Station. The results of the evaluation show that both scour jet arrays and barrier curtains may be viable methods for reducing siltation in the berthing areas. However, additional study of these technologies is recommended; in particular, full-scale tests of a spatial scour jet array and barrier curtain should be conducted at separate berths.

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INTRODUCTION

Charleston Naval Station and Charleston Naval Shipyard must dredge between 1.7 and 3.0 million yd^3 of sediment from their berthing areas each year. Most of this sediment is composed of flocculated clay material that is transported to the site via the Cooper River. Prior to the construction of the Pinopolis Dam on the Santee River in 1942, sedimentation was less of a problem at Charleston. However, the diversion of the Santee River into the Cooper River altered the hydraulic and sediment transport characteristics of the Cooper River, contributing to the current sedimentation problem. Current plans of the Army Corps of Engineers call for rediverting part of the Cooper River flow back into the Santee River; however, the ultimate effect of this action is unknown.

Sedimentation problems at Charleston Naval Shipyard and Naval Station have a significant impact on Navy expenses and operations. With current unit dredging costs at Charleston running about $2.00/$yd^3$, the annual maintenance dredging budget is between $3 and $6 million/yr. These costs are expected to rise sharply in the next decade because of rising fuel costs and the projected filling of the existing disposal area (Jenkins and Skelley, 1983).

Sedimentation-related operational problems have also been encountered at Charleston. The Navy-owned dredge, the Orion, has not been able to keep up with the rate of sedimentation at both the Naval Shipyard and the Naval Station. Inadequate water depth at the Naval Station has led to reported ship handling problems and damage to underwater appendages (Jenkins and Skelley, 1983). As a result, the Naval Station is now being dredged by privately owned dredges under a contract with the Army Corps of Engineers.

The cul-de-sac berthing configuration (i.e., berths or piers that are perpendicular to the river), which is prevalent in both the Shipyard and the Naval Station, contributes to the overall shoaling problem (see Figure 1). Ships that are berthed alongside the finger piers tend to act as partial dams to the flow in the river. Because of the low vacancy factor at Charleston, the berthed ships sharply reduce the velocity of the river currents passing through the berthing areas. As a result, the finger pier areas become natural settling basins, with high sediment deposition rates.

During the past 10 years, the Naval Facilities Engineering Command (NAVFAC) has sponsored research in the development of alternatives to conventional dredging in estuarine harbor berthing areas. The approach of the program has been to seek methods of interrupting the natural sedimentation processes, such as resuspending daily deposits of flocculated clays and excluding flocculated clay sediment fluxes from berthing areas. Two systems have been developed that use the resuspension principle: the scour jet array (Figure 2) and the vortex foil array (Figure 3). A single system has been developed that uses the exclusion principle: the passive barrier curtain (Figure 4).

Successful application of alternative sedimentation control technologies depends critically on the sedimentation environment present at a particular site. In general, the vortex foil array requires currents in excess of 50 cm/sec to be effective. Scour jet arrays can be used in areas of weaker currents; however, the circulation must be sufficient to carry the resuspended sediments out of the berthing area. The passive barrier curtain works best in areas of weak currents. Even moderate currents (about 20 cm/sec) impinging perpendicular to a curtain can impose very large loads.

In February 1983, Scripps Institution of Oceanography (SIO) conducted measurements of cross-berth currents at Quebec (Q) Pier, Charleston Naval Station (Jenkins and Skelley, 1983). The purpose of the study was to assess the suitability of the site for the future installation of a scour jet array. The scope of the study included measurements of bottom bathymetry, sediment properties, cross-berth currents, and discrete water properties. Neap tidal conditions existed during the study.

SIO's study found that the bottom had considerable relief (see Figure 5). Between the piers, the bottom had shoaled from a project depth of 35 feet to a depth of less than 25 feet. Beneath the piers, the water depth ranged from a high of 40 feet at the end of the pier to a low of 20 feet at the base. Next to the piers, the ships were sitting in individual slots or holes in the bottom. Because of this shoaled condition, the ships created a near stagnant condition in the berths. Maximum cross-berth currents in the interior of the berths alongside Q Pier were found to be 15 cm/sec or less. Maximum currents parallel to the berth were found to be about half this value.

SIO's report concluded that under shoaled conditions, a scour jet array would not be successful because the natural flushing was insufficient to carry the resuspended sediment out of the berth. It was suggested, however, that under fully dredged conditions, the flushing might be sufficiently vigorous to support a scour jet array installation.

OBJECTIVE

The objective of this study was to reassess the degree of natural flushing that occurs within a finger pier berth at Charleston Naval Station under fully dredged conditions.

The study included measurements of bathymetry, current velocities, and discrete water properties for a period of 2 days. The field study was conducted as a joint project between the Naval Civil Engineering Laboratory (NCEL) and SIO.

APPROACH

Study Site

The site of the study was the berthing area between November (N) and Papa (P) Piers, Charleston Naval Station (see Figure 6). This site was judged to be representative of the cul-de-sac berths at Charleston. The study was conducted during the week of 8 July 1984, with actual measurements made on 10 and 11 July. Figure 6 shows the position of several ships that were berthed in the study area during the time of the experiment. These included Spruance Class destroyers at berths N6, P5, and P6. A Dixie Class support ship was at berth P2.

Figure 7 shows a plot of the bottom bathymetry that existed at the study site. The depth data used to generate Figure 7 were obtained from the Public Works Department, Charleston Naval Shipyard. Figure 7 shows that unlike the conditions existing during SIO's study, the bottom was in a fully dredged condition. No depth data were available beneath the piers; however, since dredging takes place only in the berths, the depths beneath the piers probably range from 40 feet at the end of the piers to a low of 20 feet at the base of the piers.

Instrumentation

Instrumentation used in the study included eight fixed current meters, a portable profiling current meter, a pressure (tide) sensor, and a discrete water property (temperature/salinity, water sample) profiling "fish." Referring to Figure 8, the fixed current meters were deployed along the south side of November Pier, the north side of Papa Pier, and a point between the two piers. This deployment pattern provided for a comprehensive measurement of currents passing beneath the piers during ebb and flood flows in the Cooper River. The following is a brief description of each type of instrument. The fixed current meters included:

- three self-recording Aanderaa current meters
- four hard-wired Marsh McBirney electromagnetic current meters
- one self-recording Neil Brown acoustic current meter

The Aanderaa current meters were used to measure bottom currents at two points along the south side of November Pier and in the center of the area between November and Papa Piers. The Marsh McBirney current meters were used to measure bottom and midheight currents along the north side of Papa Pier. The Neil Brown current meter measured midheight currents at the end of Papa Pier, a position which was representative of undisturbed currents in the Cooper River.

Deployment methods varied with the type of current meter. The Aanderaa current meters were deployed using bottom-resting, cage-like support structures that positioned the current meters about 1 meter above the bottom (see Figure 9). The Marsh McBirney current meters were mounted on struts attached to the pier pilings about 1 meter above the bottom (see Figure 10). The Neil Brown current meter was suspended at a depth of about 5 meters above the bottom using a cable attached to the deck of the pier.

The profiling current meter and the profiling "fish" were hard-wired instruments that could be raised and lowered via manual winches. The current meter was deployed from a small boat, while the water property "fish" was deployed from a fixed position midway along the north side of Papa Pier.

Both the current meter and the water property "fish" were designed by SIO. The current meter used a Savonius rotor transducer, with optical sensors that produced a threshold velocity of 1 cm/sec. The profiling "fish" used a Beckman Instruments temperature and salinity probe. Each instrument had its own deck readout unit.

The tide was measured using a Statham pressure sensor mounted in a stilling well. The dynamic range of the pressure sensor was 13 to 33 psia. The stilling well consisted of a 6-inch-diam, 20-foot-long polyvinyl chloride (PVC) pipe, with a helical-shaped pattern of 5/8-inch holes drilled in its base. Both the pressure sensor and the hard-wired current meters were connected to a high-density digital data logger located midway along the north side of Papa Pier. The sampling interval was 0.5 second for all instruments.

RESULTS

Tides, currents, and discrete water properties were measured from 10 to 12 July. During this time, the self-recording current meters gathered data from about 1300 hours on 20 July to 0900 hours on 12 July. Because of problems with the data logger, data from the hard-wired current meters and the pressure sensor were obtained in two segments: from 1145 hours on 10 July to 0230 hours on 11 July and from 0955 hours to 1830 hours on 11 July. The 10 July data cover almost a complete tidal cycle and include both high and low tides. The 11 July data cover only about two-thirds of a tidal cycle and include only low tide. Although data were obtained from the self-recording current meters for the full duration of the experiment, the data analysis focused on the two data segments during which the greatest number of instruments were operational.

Tides

Figures 11 and 12 show the sea surface elevation (tide) data measured on 10 and 11 July. Both sets of data show that spring tide conditions existed during the experiment. The tide range on 10 July was about 1.85 meters. This compares favorably with the predicted range of 1.80 meters in Charleston Harbor. On 10 July, high tide occurred at 1940 hours, compared with the predicted time of 1943 hours. Note that the predicted time was obtained by using a method suggested by the Public Works Department (i.e., add 0.5 hour to the predicted time for Charleston Harbor). On 11 July, low tide occurred at 0200 hours and then again at 1330 hours. This can be compared with the predicted times of low tide of 0156 hours and 1354 hours. In general, it appears that the rule-of-thumb suggested by Public Works is quite accurate.

Currents

Although eight current meters were deployed during the study, only five were operational for the full duration of the experiment and one was operational intermittently. The fully operational current meters were the two bottom-resting Aanderaa current meters along the south side of November Pier, the midheight Neil Brown current meter at the end of

Papa Pier, and the bottom-resting Marsh McBirney current meters at the base and midpoint on the north side of Papa Pier. The midheight Marsh McBirney current meter midway along the north side of Papa Pier was only periodically operational because of interference from the neighboring ships' radars. The two current meters that failed were the bottom-resting Aanderaa in the center of the area between November and Papa Piers and the bottom-resting Marsh McBirney near the end of the north side of Papa Pier.

The fixed current meter data measured on 10 July are shown in Figures 13 through 18. Similar data measured on 11 July are shown in Figures 19 through 23. The data in each figure are presented in terms of a time history of the current flowing parallel to the pier (positive x is directed away from the bank) and the current flowing perpendicular to the pier (positive y is directed upriver). In a few cases, only the y-direction current component was measured because of the design of several of the mounting brackets.

The current meter data from the end of Papa Pier (midheight) (Figures 13 and 19) are most indicative of the undisturbed current in the river. These data show that the peak current in the river occurs during ebb tidal flow. The magnitude of the peak ebb current on both days was about 60 cm/sec (1.2 knots), while in contrast the magnitude of the peak flood current reached only 30 cm/sec (0.6 knot). On 10 July, the measured time of slack water (high) was about 2040 hours versus a predicted time of 2100 hours. On 11 July, the measured time of low slack water was 1520 hours versus a predicted time of 1523 hours, and the measured time of high slack water was 2130 hours versus a predicted time of 2149 hours. In general, the measured time was about 20 minutes earlier than the predicted time during high slack water and the same time during low slack water.

To best understand the overall circulation pattern that occurs in the November and Papa Piers berthing areas, one must consider the current meter data as a whole, focusing on conditions during flood and ebb flow in the river. Data from 10 July are indicative of flood and ebb currents about high slack water, while the data from 11 July are indicative of ebb and flood currents about low slack water.

Considering the x-direction (parallel to the piers) current during flood flow in the river, the flow is negative (i.e., into the berth). Near the end of the piers, maximum currents reach about 25 cm/sec on the south side of November Pier and 10 cm/sec on the north side of Papa Pier. Further into the berth, near the base of the piers, maximum current decreases to about 15 cm/sec on the south side of November Pier. No x-direction current data were available for the interior of the berth on the north side of Papa Pier.

Throughout the berth, but most pronounced in the interior, was an apparent internal seiching motion during flood flow. The evidence for this is the high amplitude oscillation (20 cm/sec peak-to-peak) shown in the data from the base of the November Pier (Figures 17 and 22). To a lesser degree, the seiching motion is also evident in the data at the end of the November Pier (Figures 18 and 23) and at the end of the Papa Pier (Figures 14 and 20). The period of oscillation initially appears to be about 40 minutes, increasing to about 60 minutes as the tide approaches the end of flood flow.

Considering the y-direction (perpendicular to the piers) currents during flood flow, the flow is generally positive (i.e., upriver) throughout the berth. On the south side of November Pier, maximum currents reach about 10 cm/sec in the outer part of the berth and less than 2 cm/sec in the interior of the berth. Similarly, on the north side of Papa Pier, cross-pier currents are about 10 cm/sec in the outer part of the berth and less than 2 cm/sec at the midpoint of the berth.

During ebb river flow, x-direction currents are positive (i.e., flowing out into the river). On the south side of November Pier, currents reach a maximum of 10 cm/sec in the outer portion of the berth and a maximum of 5 cm/sec in the interior. On the north side of Papa Pier, ebb currents reach a maximum of 5 cm/sec in the outer portion of the berth. No x-direction current data are available for the inner portion of Papa Pier.

The y-direction (cross-berth) currents in the berth move in the downriver (south) direction during ebb river flow. On the south side of November Pier, ebbing currents reach a maximum of 7 cm/sec in the outer portion of the berth and less than 2 cm/sec in the interior. On the north side of Papa Pier, currents reach a maximum of 10 cm/sec in the outer portion of the berth and less than 2 cm/sec in the interior.

Periodically during 11 July, vertical profiles of current were measured at different points within the berth using the profiling current meter. In general, the data showed that in the outer portion of the berth, current speeds increased with height above the bottom. For example, at the extreme end of Papa Pier, Figure 24 shows the current speed increasing from 30 cm/sec at 1 meter above the bottom to 73 cm/sec at the surface. In the interior of the berth, the currents are more confused, reflecting the blocking effect of the ship hulls. For example, Figure 25 shows a current profile taken on the north side of Papa Pier during flood flow. A destroyer was berthed on the opposite side of the pier. The blockage effect of the hull of the ship is quite pronounced in the current profile, with bottom currents reaching 17 cm/sec and surface currents dropping to 7 cm/sec.

The profiling current meter was also used to measure the strength of surface currents during peak ebb flow at the ends of K, L, N, and P Piers. The maximum current (120 cm/sec) was measured at the end of K Pier, while the minimum current (70 cm/sec) was measured at the ends of L and N Piers. Table 1 contains a summary of these data.

In summary, tidal currents in the cul-de-sac berths are strongly influenced by the blocking effect of ship hulls. While peak cross-berth currents at the ends of the piers reach speeds in excess of 70 cm/sec, cross-berth currents within the berth are sharply reduced. During both flood and ebb flow, these currents reach speeds of about 10 cm/sec in the outer part of the berth and less than 2 cm/sec in the interior of the berth. Currents flowing parallel to the piers appear to dominate the circulation within the berth. This is particularly true during flood flow, when peak magnitudes reach 25 cm/sec in the outer portion of the berth. This strong inflow creates an internal seiching motion that is most pronounced in the interior of the berth. During ebb flow, currents flowing parallel to the pier are weaker but still significant (5 to 10 cm/sec).

Discrete Water Properties

Profiles of temperature, salinity, and sediment concentration were measured between 0840 and 1840 hours on 11 July. All of the profiles were made from a fixed point midway along the north side of Papa Pier. Figures 26 through 31 contain the measured profile data. These data are divided into profiles measured during flood and ebb tide conditions.

Referring to Figures 26 and 27, the profiles of water temperature show relatively small changes with time and depth. In general, the temperature variation during flood flow was greatest, ranging from a low of about 28°C at the bottom to a high of about 29°C at the surface (see Figure 26). During ebb flow (Figure 27), the distribution of temperature was more uniform, with the temperature ranging from a low of 28°C at the bottom to a high of 28.2°C at the surface. Temporal variations were less significant, showing a range of about 0.4°C.

Compared with the temperature profiles, the salinity profiles show a significantly wider range of variation. Referring to Figure 29, the salinity during flood tide increased sharply with height above the bottom. The salinity ranged from a high of 20 $^{o}/oo$ at the bottom to a low of 7 $^{o}/oo$ at the surface. The profiles clearly show the progressive intrusion of the salt wedge up the Cooper River during flood flow. Figure 29 shows that during ebb flow the situation is reversed, with the salt wedge progressively moving down the Cooper River. Recalling the evidence for internal seiching motions, the sharp discontinuity in salinity associated with the upper surface of the salt wedge would provide a suitable density interface to support such a motion.

Figures 30 and 31 show the measured sediment concentration profiles during flood and ebb river flow. In general, these profiles show a decrease in sediment concentration with increasing distance above the bottom. Overall suspended sediment levels range from a high of about 45 mg/l at the bottom to a low of about 10 mg/l at the surface. Considering the degree of experimental scatter in the data, there appears to be little difference in the profile between flood and ebb conditions. The relatively low levels of sediment concentration suggest that conditions during the study did not correspond to a period of high sedimentation.

DISCUSSION

Successful application of either the scour jet array or the curtain barrier in the cul-de-sac berthing areas at Charleston depends critically on the circulation patterns within the berths. For jet arrays, the most important factor is the degree of flushing that is available to carry newly resuspended sediments out of the berthing area. For barrier curtains, the primary factors are the magnitude of the currents in the berthing area and the degree of stratification present.

Assuming the berthing area between the November and Papa Piers to be typical of all of the cul-de-sac berths, the measured current meter data suggest that during spring tides the primary flushing mechanisms are the currents flowing parallel to the piers. These currents are directed into the berth during flood tide and out of the berth during ebb tide. The latter are of primary interest to the operation of a jet array.

Bottom currents inside the berthing area begin to ebb about 2 hours after high tide and continue until about 1.5 hours after low tide. During this time, the mean velocity of the current flowing out into the river is about 3 cm/sec in the interior of the berth and 7 cm/sec near the outer end of the berth. If the following is true,

1. The jet array is designed to sweep the sediment from the back of the berth outward into the Cooper River.

2. The average outward flow is 5 cm/sec and the nominal duration of ebb flow is 5 hours.

3. The length of the berth is 366 meters.

then the available flushing is more than adequate to carry the resuspended sediment out of the berth and into the river (i.e., 0.05 x 5 x 3,600 = 900 m > 366 m). On this basis, jet arrays appear to be a viable option for controlling sedimentation in the cul-de-sac berthing areas at Charleston.

For a barrier curtain to perform satisfactorily, the stratification must be sufficiently developed to prevent the sediment-ladened bottom water from moving up and over the top of the curtain during flood flow in the river. Referring to Figure 32, Turner (1973) has shown that a denser bottom layer can be prevented from passing over an obstacle provided the densimetric Froude number, F_r, is less than 0.25. The densimetric Froude number may be estimated as:

$$F_r = \frac{Q}{g'^{1/2}\, h^{3/2}} \tag{1}$$

where: Q = rate of flow entering the berth per unit width, m^3/sec-m

g' = reduced gravity (i.e., $(\Delta\rho/\rho)g$), m/sec^2

h = height of curtain above the density interface, m

Based on the measured data at Charleston,

Q = 0.105 m^3/sec-m
h = 8 m
g' = 0.046 m/sec^2

Combining the above data with Equation 1, the densimetric Froude number, F_r, is found to be 0.0216, which is less than 0.25. Thus, the curtain will prevent the denser bottom water from entering the berth.

Lateral loads are also an important consideration in the design of a barrier curtain. The lateral load on a curtain barrier depends critically on the magnitude of the component of current flowing perpendicular to the curtain. As the lateral load increases, the size of the float and anchor elements must be increased to keep the curtain upright. In the case of Charleston, the peak magnitude of the normal current that would impact the curtain was 25 cm/sec.

Bailard (1981) developed a mathematical model to predict float and anchor sizes required for a two-story curtain as a function of incident current speed. Figure 33 is a plot of float diameter (upper and lower) and anchor as a function of current speed. (Note that the anchor has a rectangular cross section with a width-to-height ratio of 4.) The total height of the curtain is 10 meters, the height of the lower section is 5 meters, and the deflection angle of the curtain is 0.1 radian. Assuming a peak incident velocity of 25 cm/sec, the diameter of the surface float would need to be 60 cm, the diameter of the lower float would need to be 80 cm, and the width of the anchor would need to be 120 cm. Alternatively, if the deflection angle were allowed to increase to 0.3 radian, these sizes could be reduced by about 40% (see Figure 34).

In general, the above dimensions are large but not unacceptable. Barrier curtains appear to be a viable option for Charleston provided they can be recessed into the berth sufficiently to be out of the maximum river currents. These currents reach speeds of up to 150 cm/sec during peak ebb flow. It is not known at this time whether currents of this speed will induce curtain flutter.

CONCLUSIONS

1. The principal flushing mechanisms for carrying resuspended sediments out of cul-de-sac berthing areas at Charleston are currents flowing parallel to the piers. These currents average about 15 cm/sec during flood flow and 5 cm/sec during ebb flow. Cross-berth currents during both flood and ebb flow are weak to negligible within the berth.

2. The above flushing is sufficiently vigorous to allow jet arrays to be used to prevent siltation in the cul-de-sac berthing areas. The most economical type of jet array would be an area array with the jets distributed across the bottom of the berthing area.

3. The magnitude of the currents in the interior of the berth, coupled with a high degree of stratification, suggests that barrier curtains may also be a viable method of reducing siltation in the cul-de-sac berthing areas. Critical questions affecting the application of barrier curtains at Charleston include:

   (a) How can curtains be deployed without interfering with ship operations?

   (b) Is there an operationally acceptable method of opening and closing curtains at Charleston, especially when ships, at times, project beyond the end of the piers?

   (c) What is the best location within the berth for a curtain?

   (d) Will curtain flutter be a problem?

4. Because of the operational issues involved, the above questions can best be answered through a full-scale test program.

RECOMMENDATION

Based on these conclusions, it is recommended that additional study be given to applying scour jet array and barrier curtain technologies to the sedimentation problems at Charleston Naval Station. In particular, it is recommended that full-scale tests of a spatial scour jet array and a barrier curtain be conducted at separate berths.

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Bailard, J.A. (1981). "A design for a sediment control curtain," in Proceedings of the Second NAVFAC Symposium on Dredging and Sedimentation Control, 23-24 Jun 1981, La Jolla, Calif.

Jenkins, S.A., and Skelley, D.W. (1983). Jet array site suitability study at Charleston Naval Station, Naval Civil Engineering Laboratory, Contract Report. La Jolla, Calif., Scripps Institution of Oceanography, Dec 1983. (Contract No. N62474-82-C-8300)

Turner, J.S. (1973). Buoyancy effects in fluids. Cambridge, Great Britain, Cambridge University Press, 1973.

Table 1. Surface Currents Measured at the End of K, L, N, and P Piers During Peak Ebb Flow on 11 July 1984

Pier	Time	Current Speed (cm/sec)
K	1220	120
L	1230	70
N	1235	70
P	1237	75

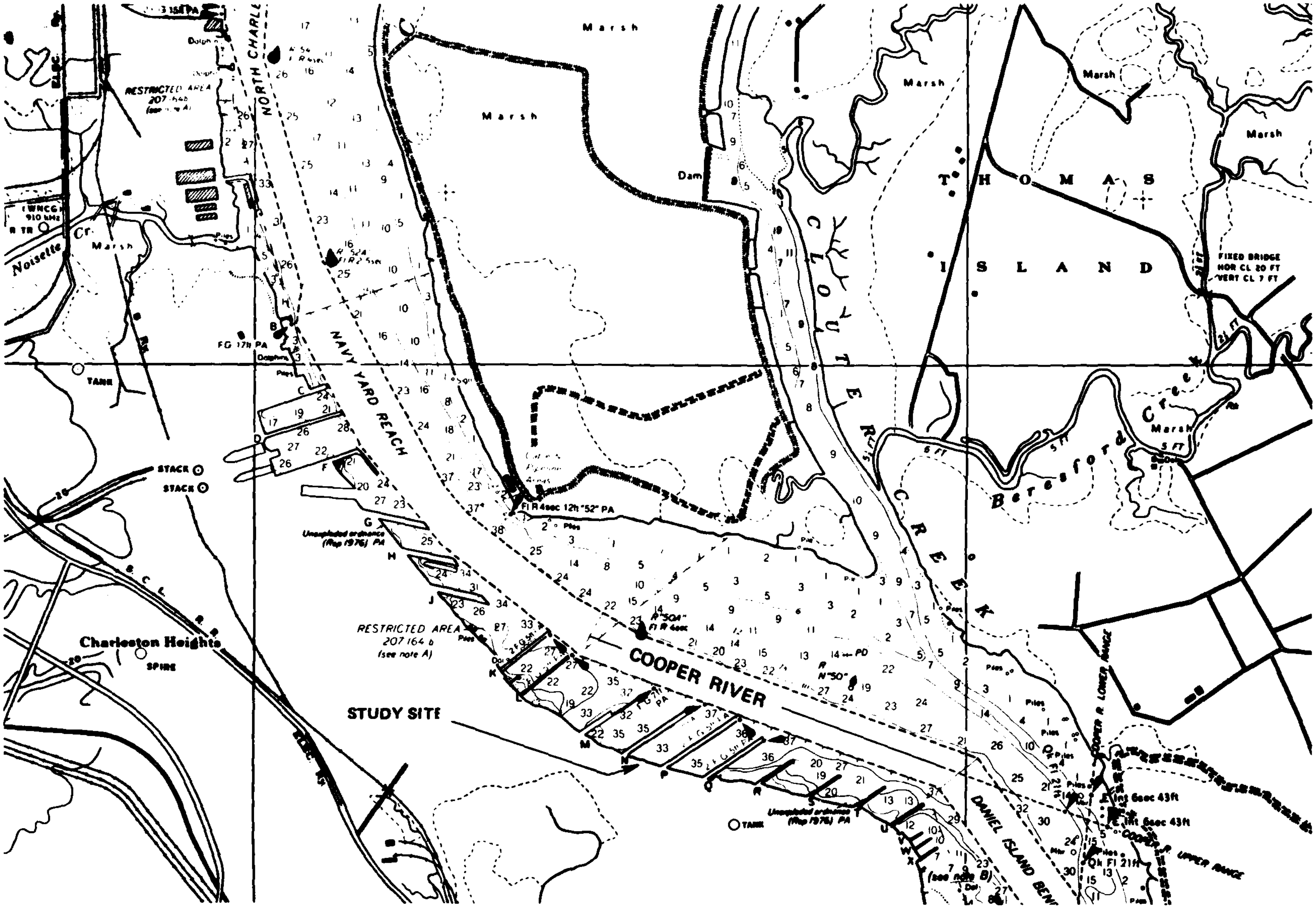

Figure 1. Cul-de-sac berths that are formed by piers oriented perpendicular to the Cooper River contribute to the overall sedimentation problem at Charleston Naval Station.

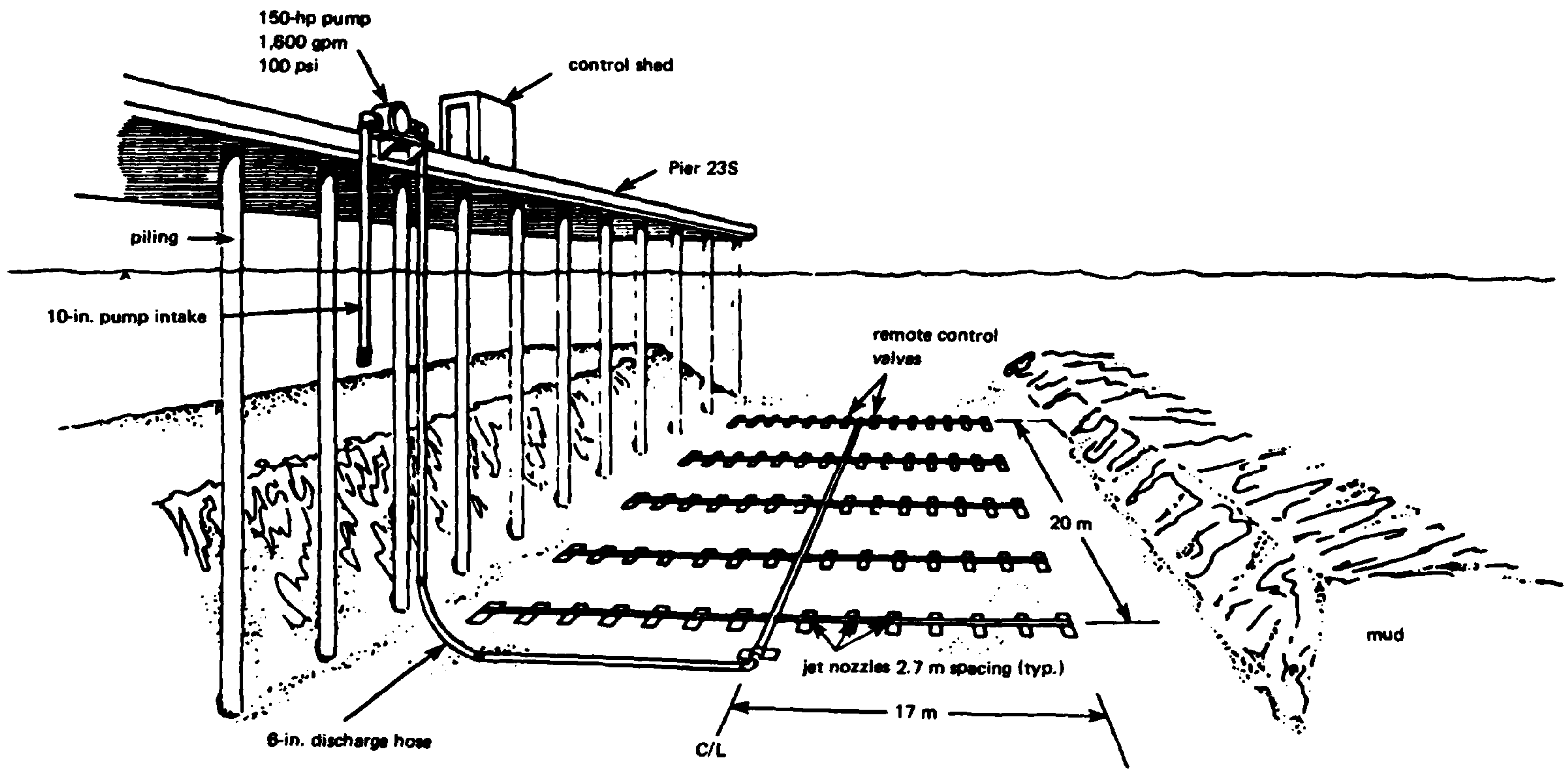

Figure 2. Schematic view of the spatial scour jet array tested at Mare Island Naval Shipyard.

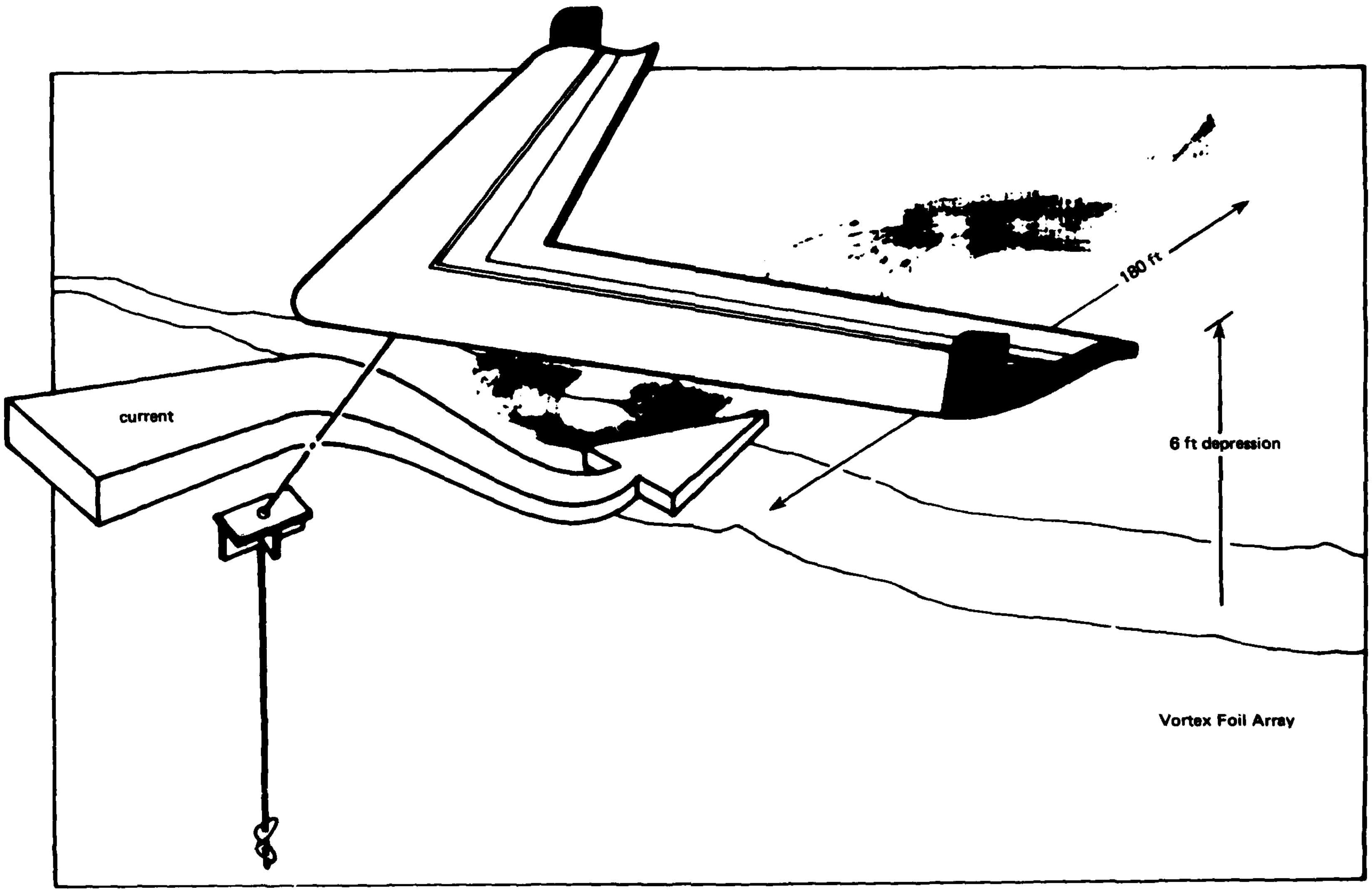

Figure 3. Schematic representation of the tidal flow past a vortex foil creating a zone of scour behind the foil. The foils are used in arrays to prevent sediment deposition.

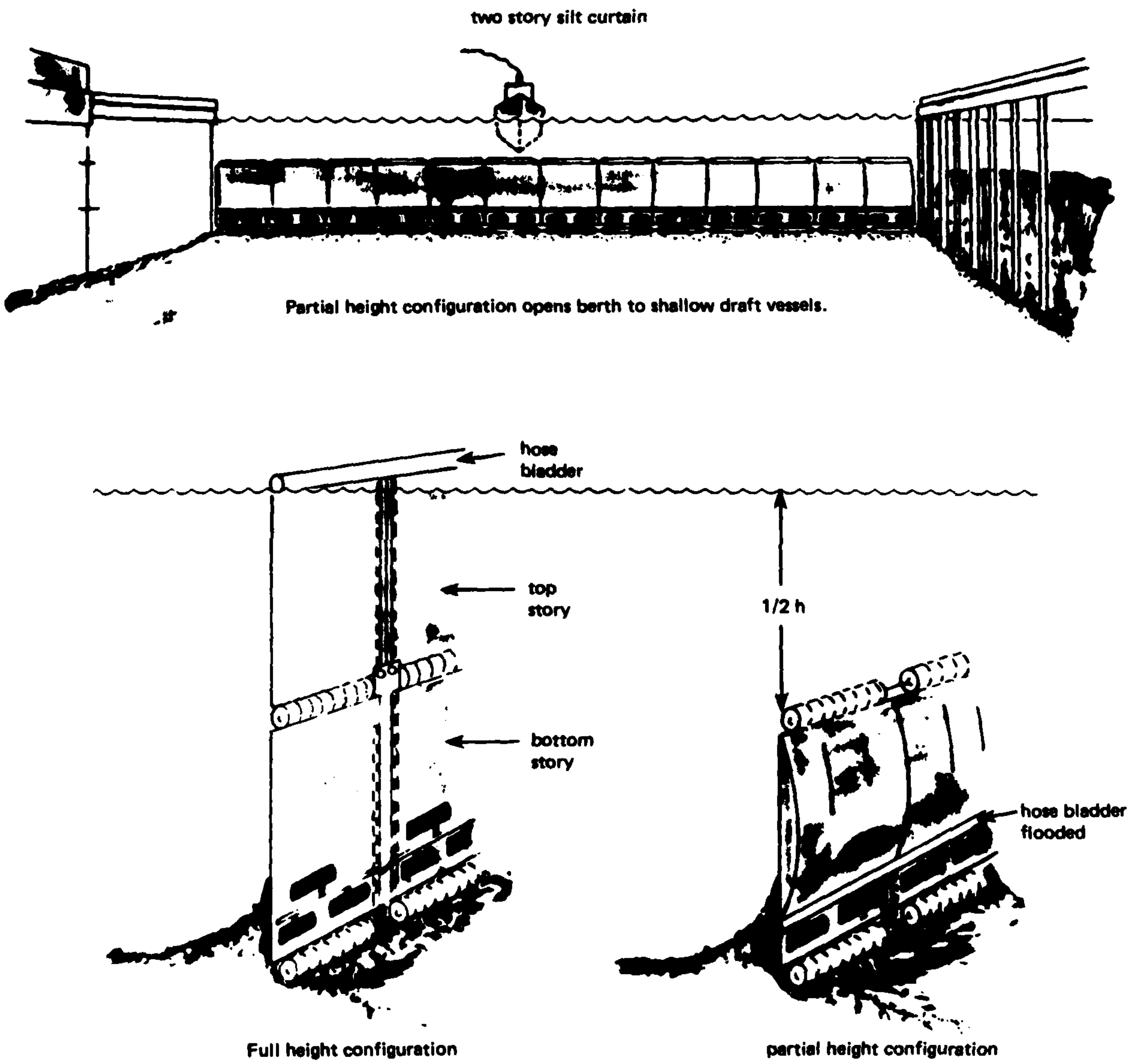

Figure 4. Schematic view of pneumatic two-story curtain barrier. The upper section can be lowered independently of the bottom section to allow the transit of shallow vessels. Both sections are raised and swung out of the way to allow the transit of a deep draft vessel.

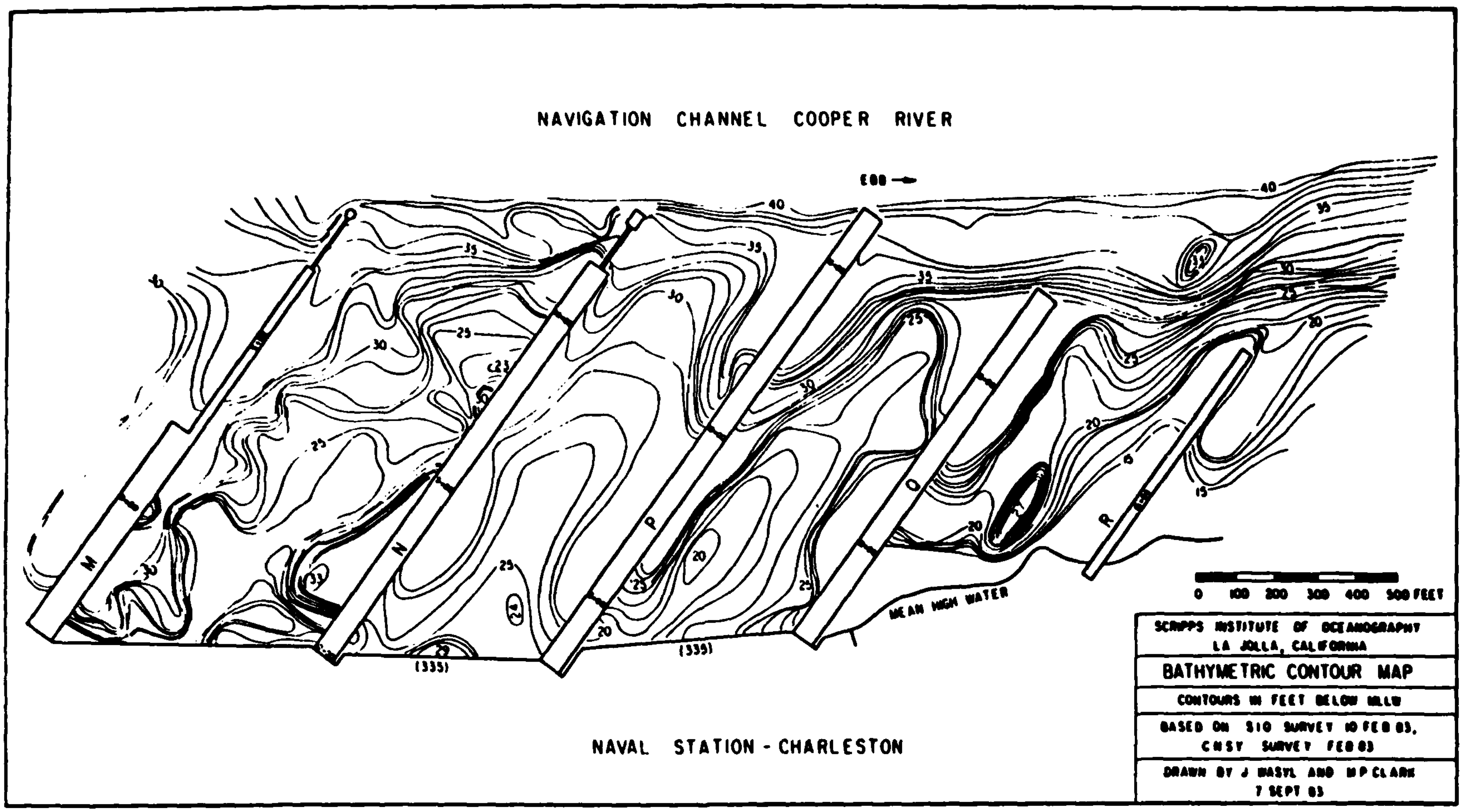

Figure 5. Composite bathymetric contour map of the Naval Station area from M Pier through R Pier. Survey done on 10 Feb 1983.

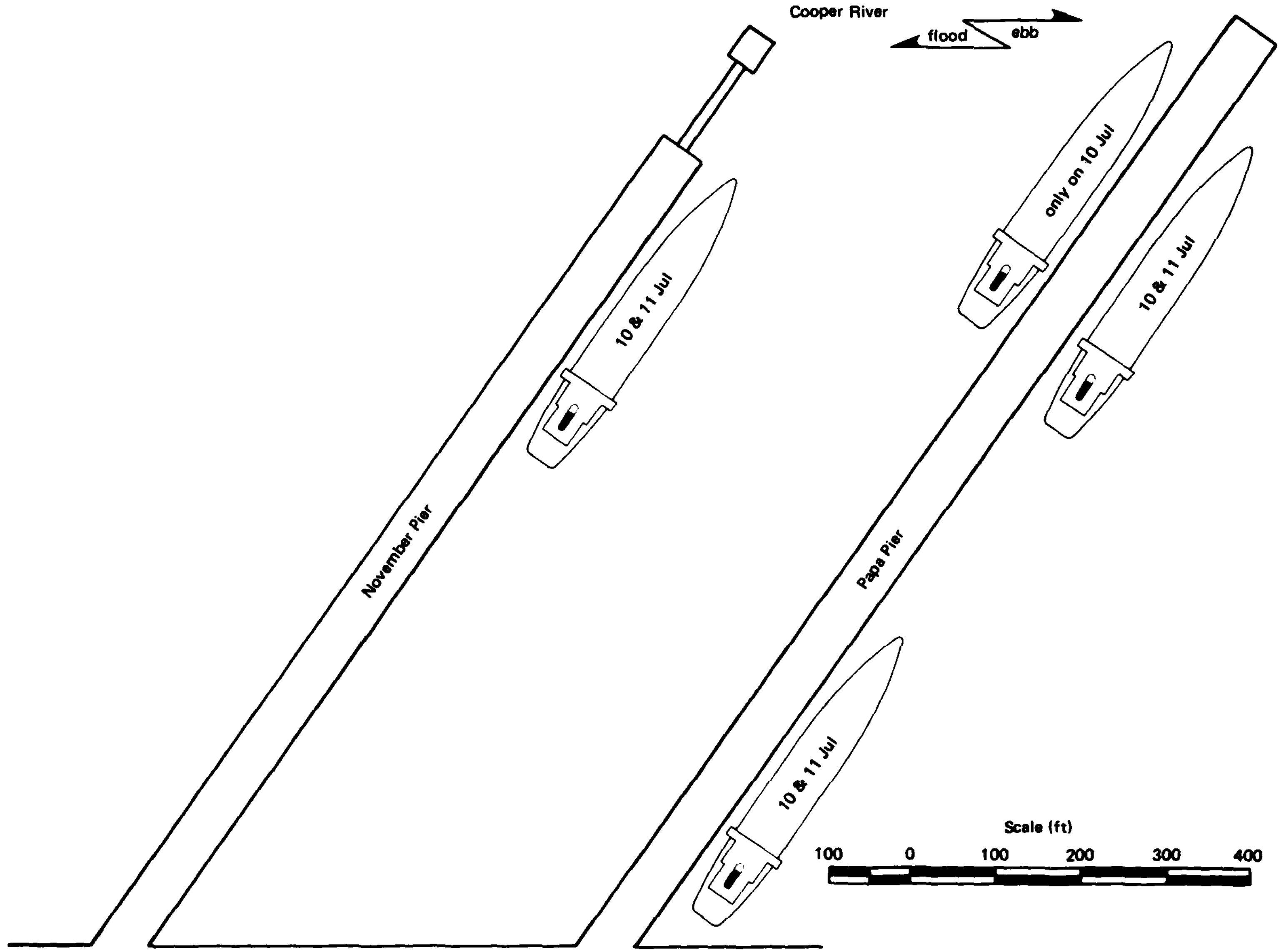

Figure 6. Plan view of study area between November and Papa Piers showing locations of berthed ships.

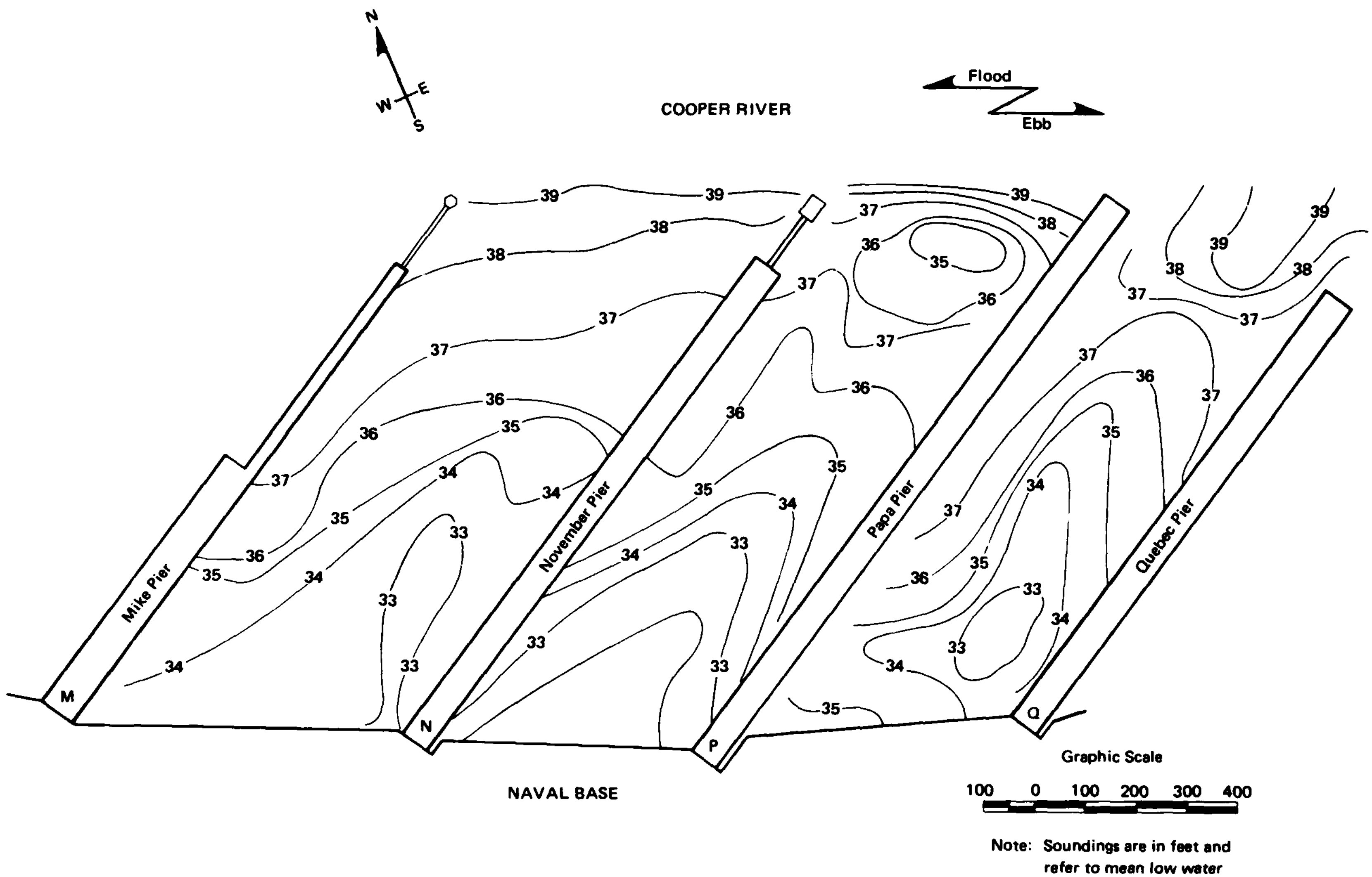

Figure 7. Composite bathymetric contour map of the study site. Survey was conducted on 6 Jun 1984.

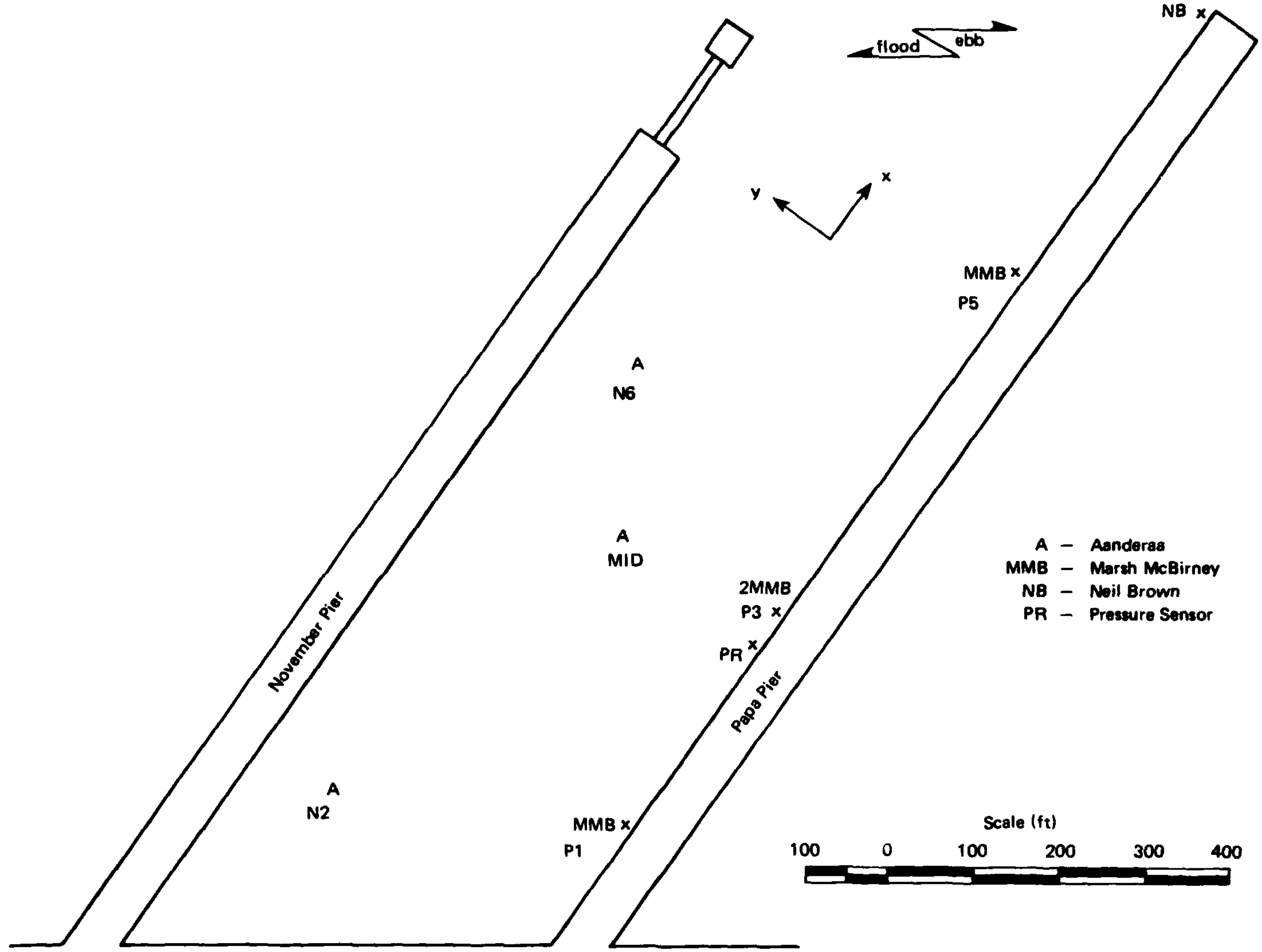

Figure 8. Plan view of study site showing the location of all instruments.

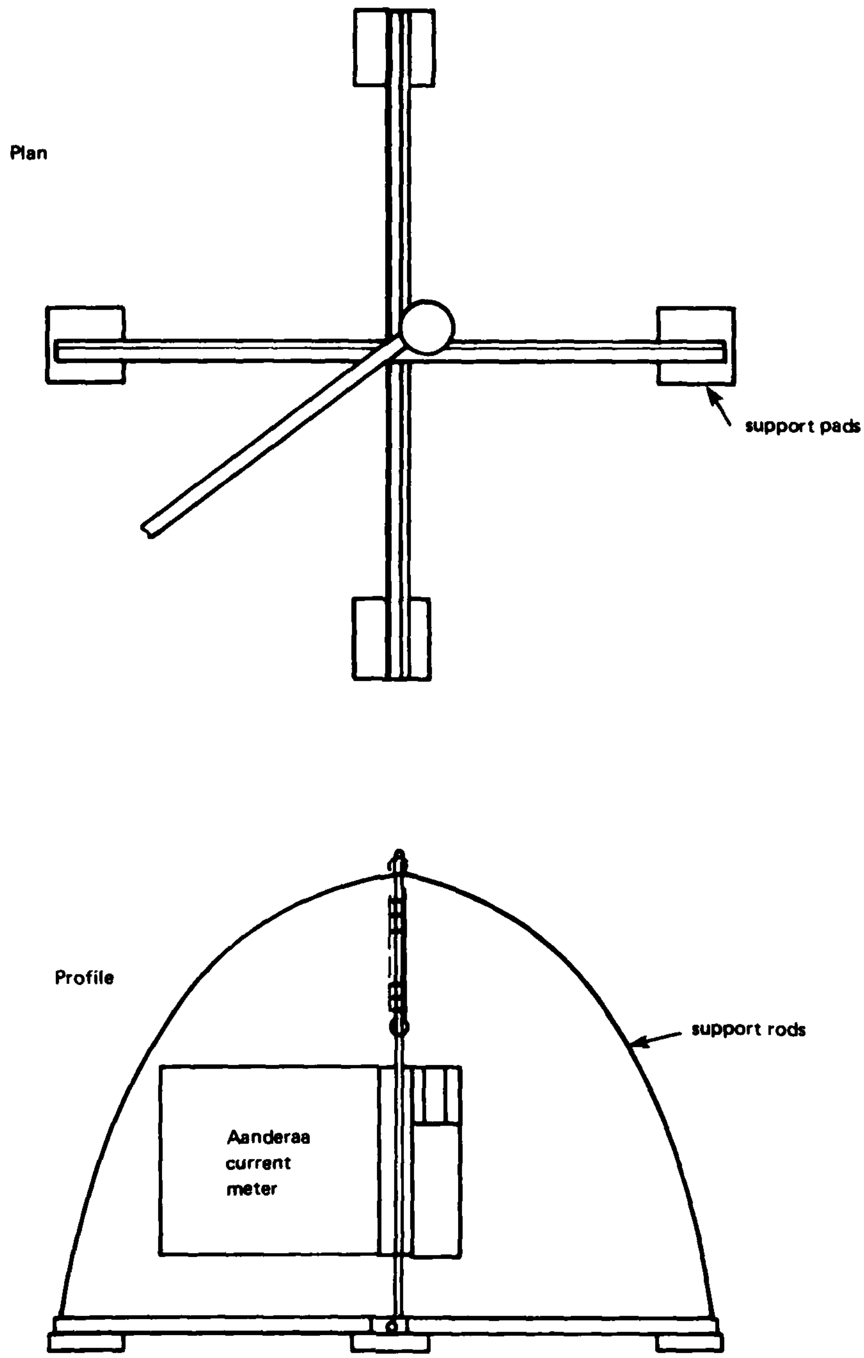

Figure 9. Schematic diagram showing the support cage structure for the Aanderaa current meters.

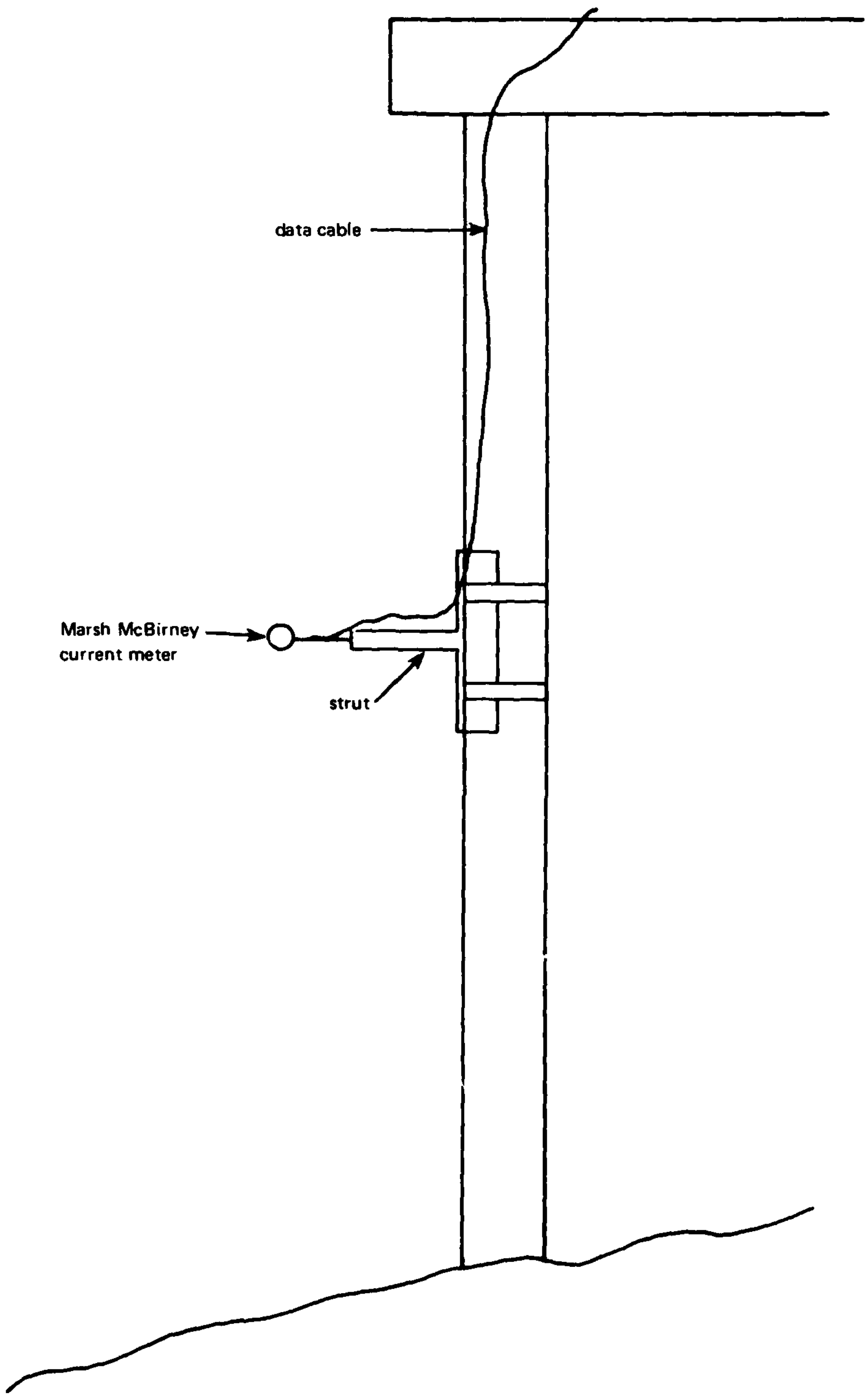

Figure 10. Schematic diagram showing the mounting strut for the Marsh McBirney current meter at the end of Papa Pier.

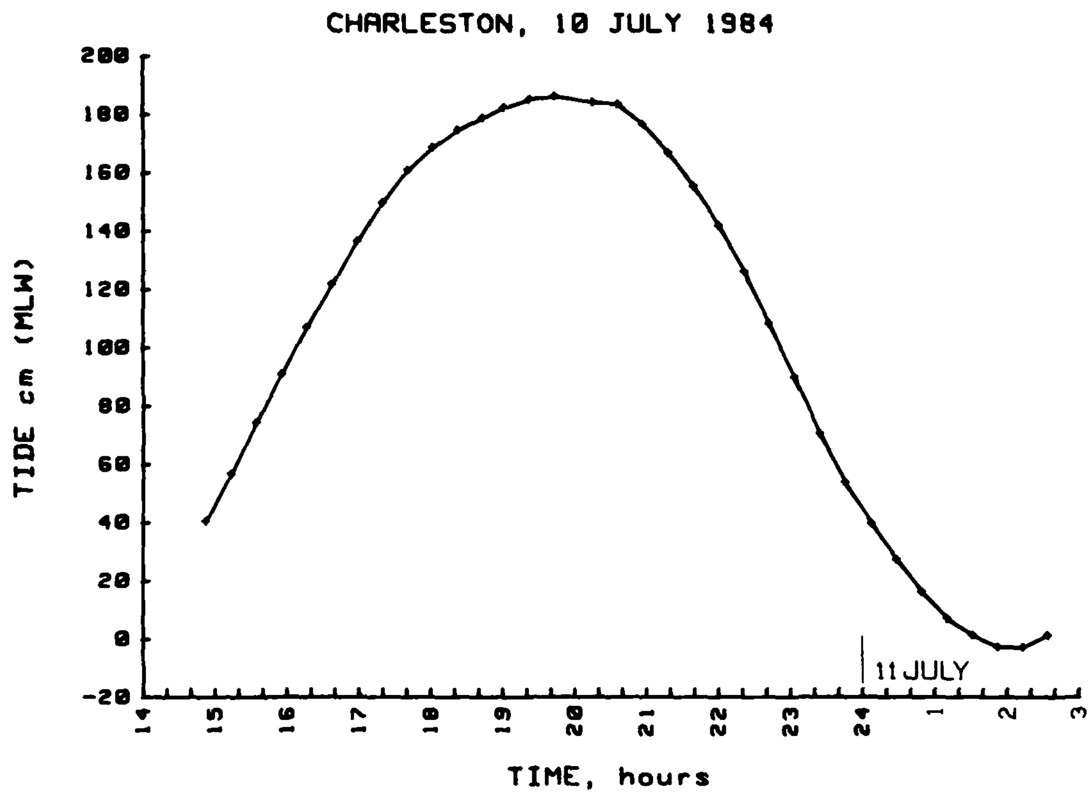

Figure 11. Measured sea surface elevation at Papa Pier on 10 Jul 1984.

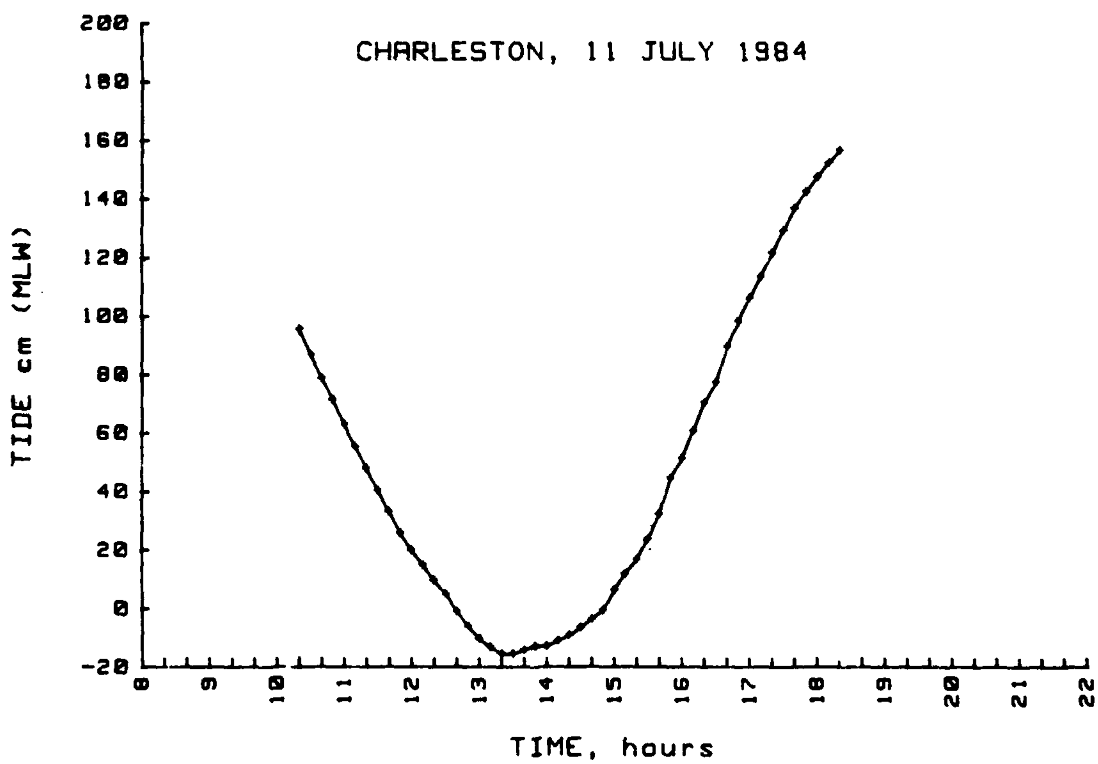

Figure 12. Measured sea surface elevation at Papa Pier on 11 Jul 1984.

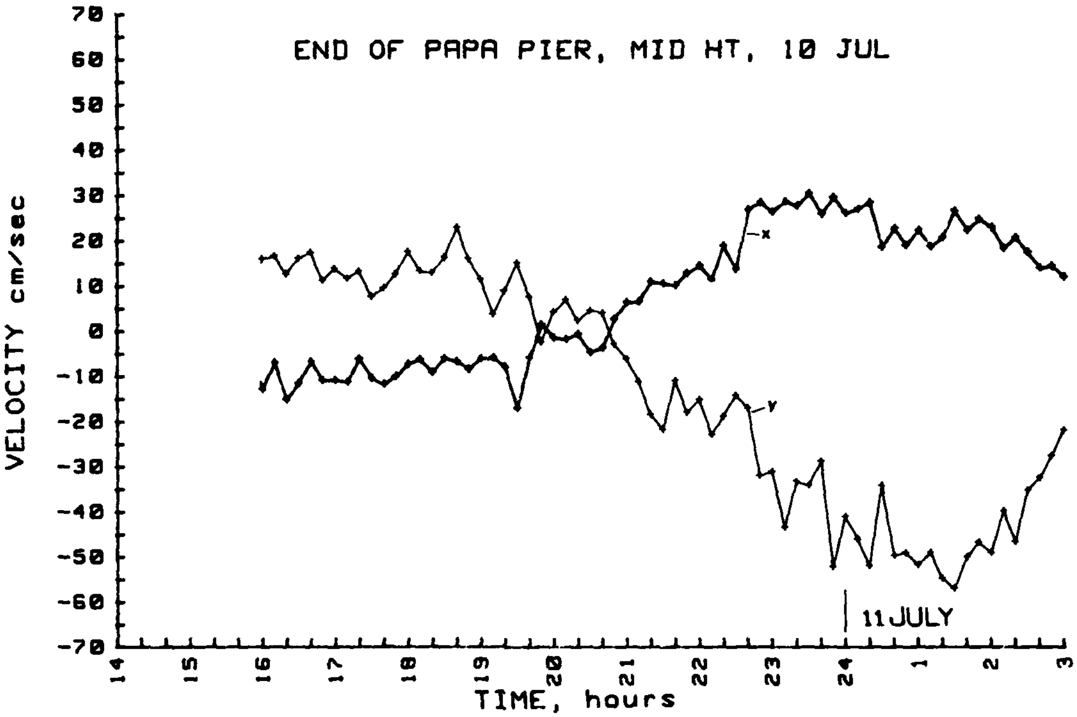

Figure 13. Measured parallel- (x) and cross-berth (y) currents at the end of Papa Pier on 10 Jul 1984. The current meter was at middepth and is representative of flow in the river.

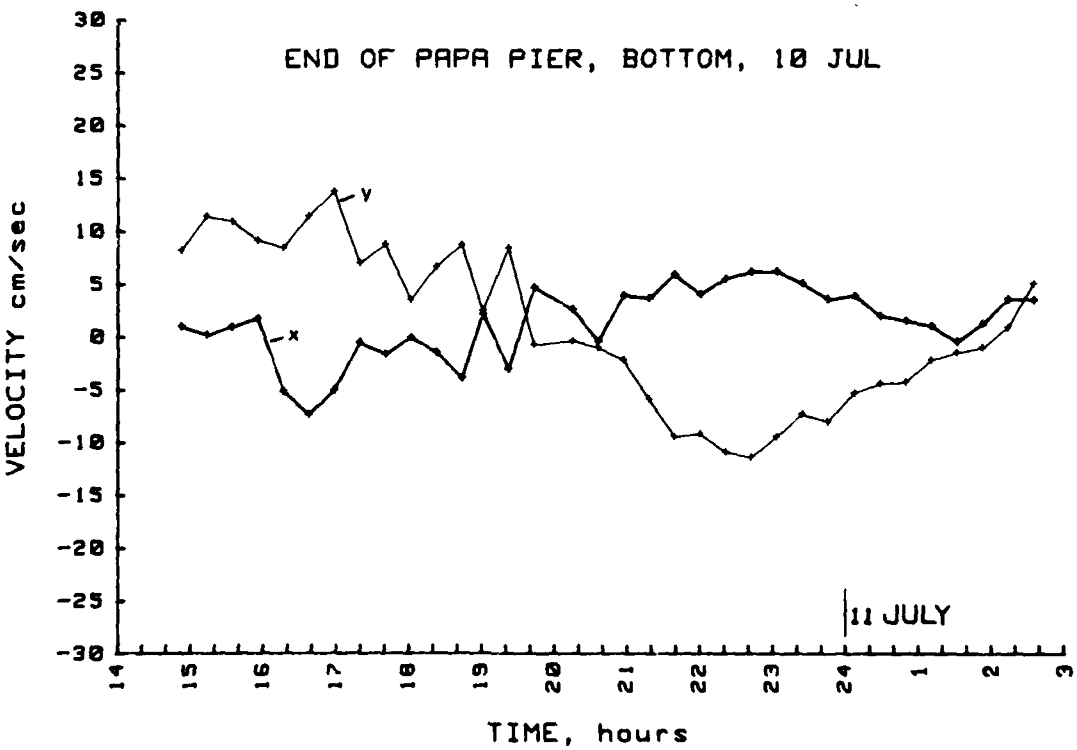

Figure 14. Measured parallel- (x) and cross-berth (y) bottom currents at the end of Papa Pier on 10 Jul 1984.

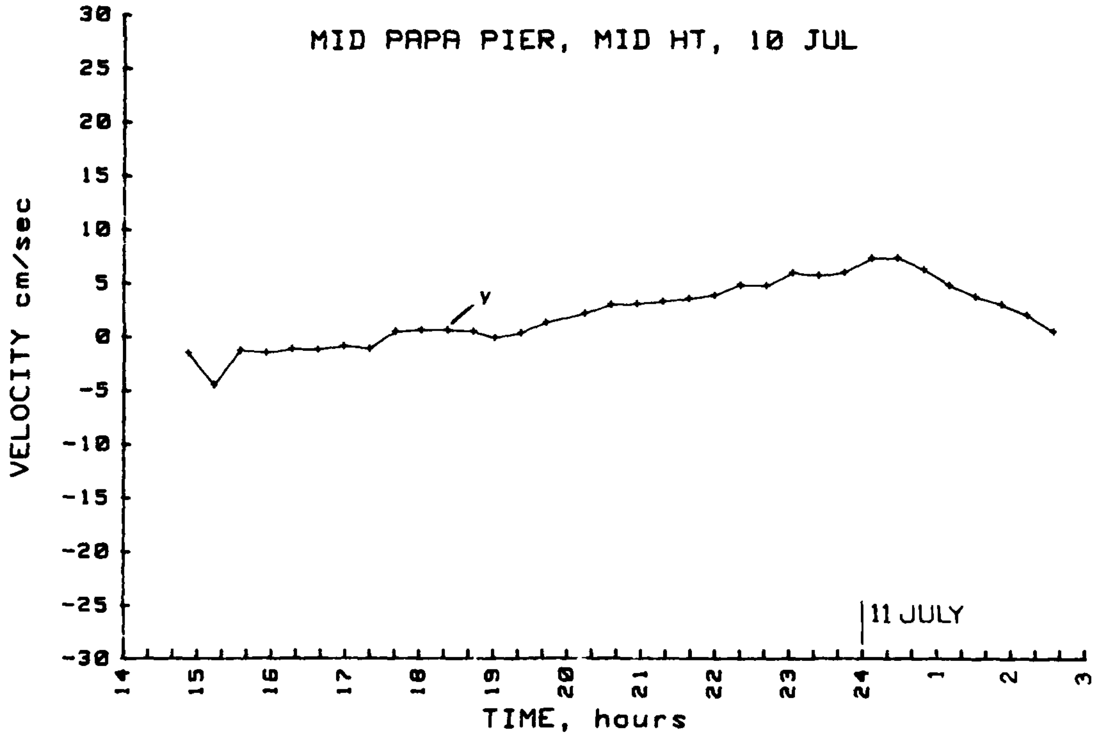

Figure 15. Measured cross-berth (y) current midway along Papa Pier on 10 Jul 1984. The current meter was at middepth.

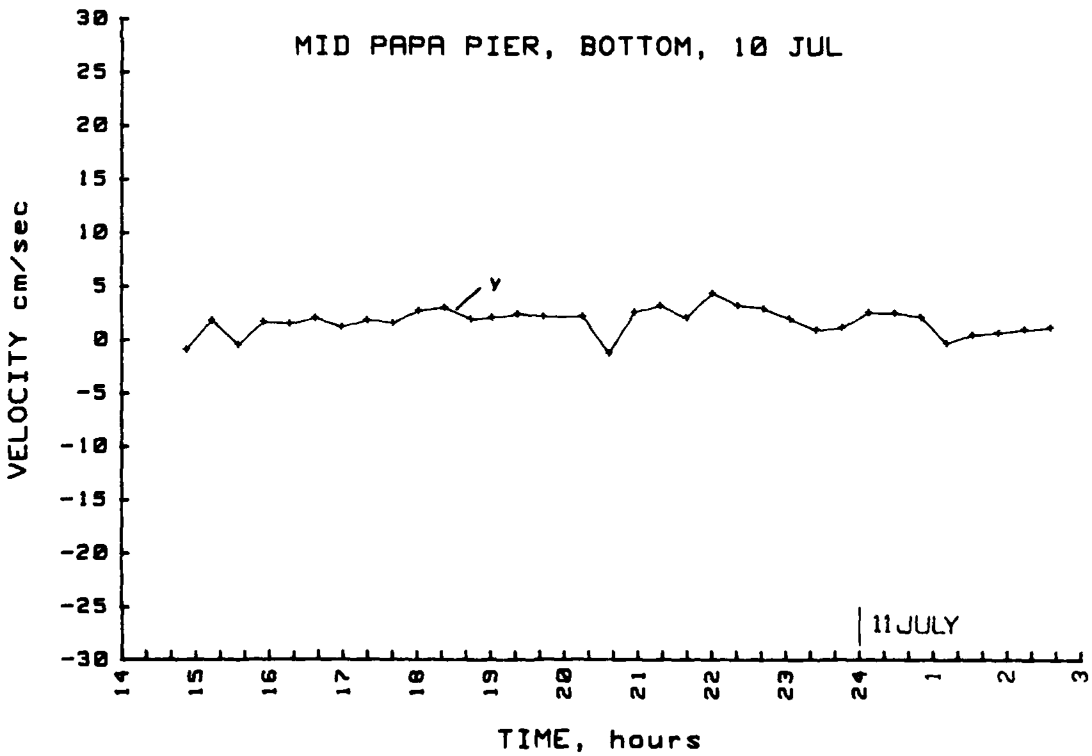

Figure 16. Measured cross-berth (y) bottom currents midway along Papa Pier on 10 Jul 1984.

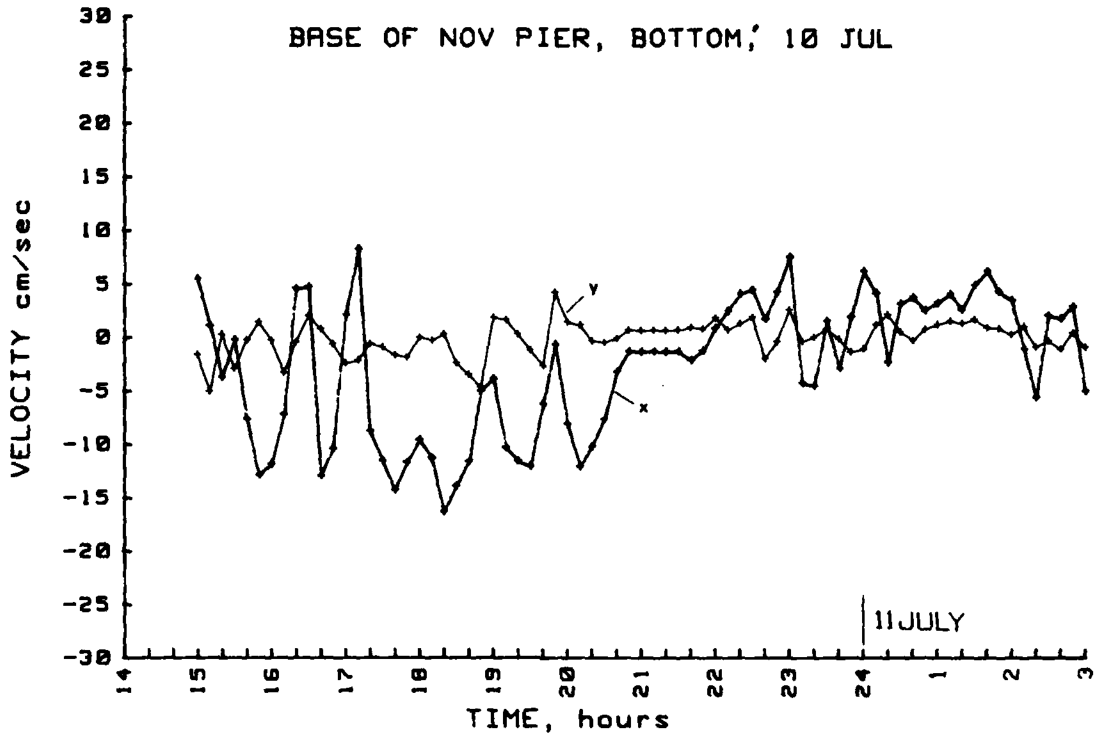

Figure 17. Measured parallel- (x) and cross-berth (y) bottom currents at the base of November Pier on 10 Jul 1984.

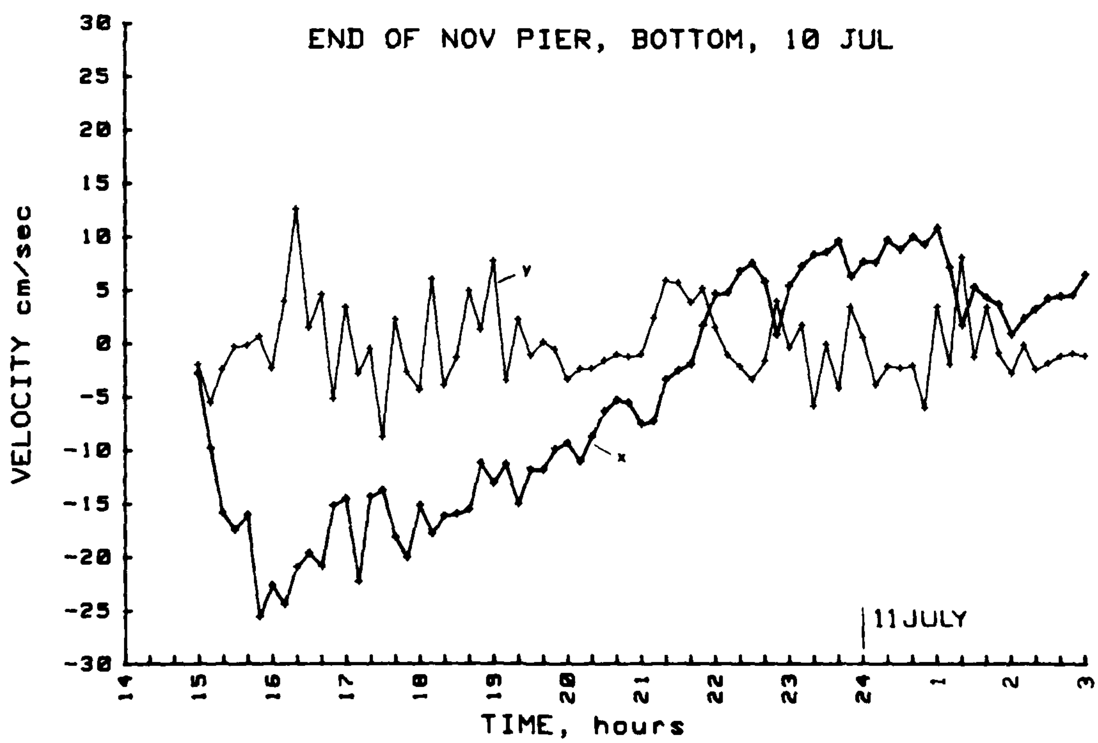

Figure 18. Measured parallel- (x) and cross-berth (y) bottom currents currents at the end of November Pier on 10 Jul 1984.

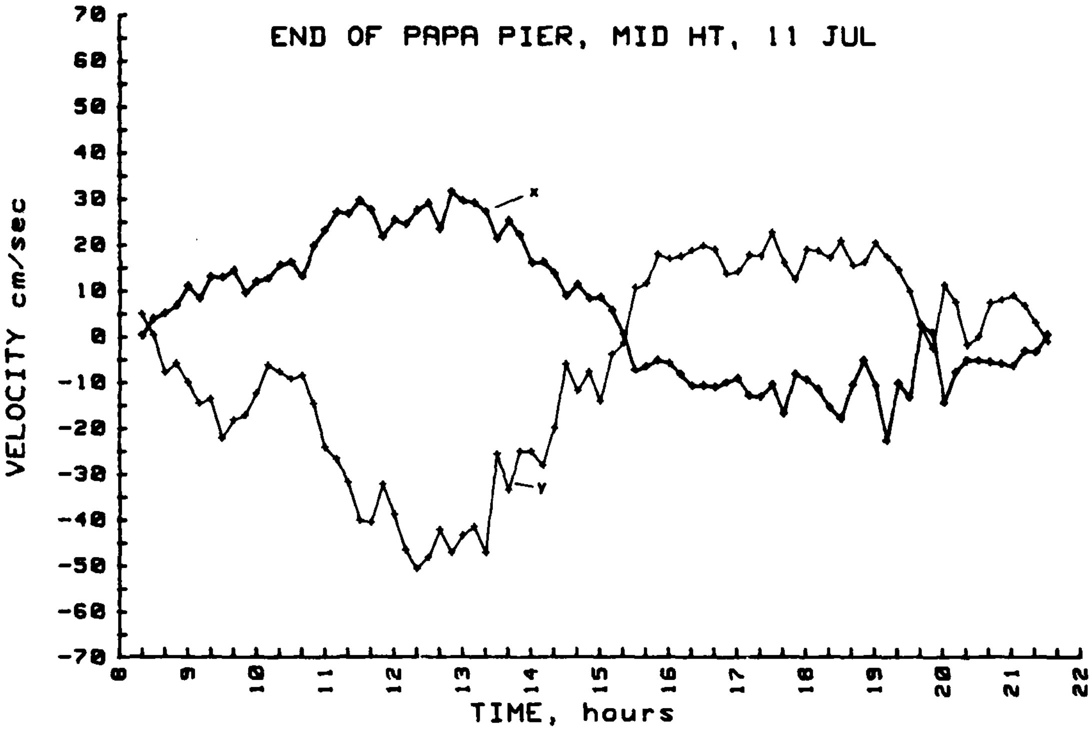

Figure 19. Measured parallel- (x) and cross-berth (y) currents at the end of Papa Pier on 11 Jul 1984. The current meter was at middepth and is representative of flow in the river.

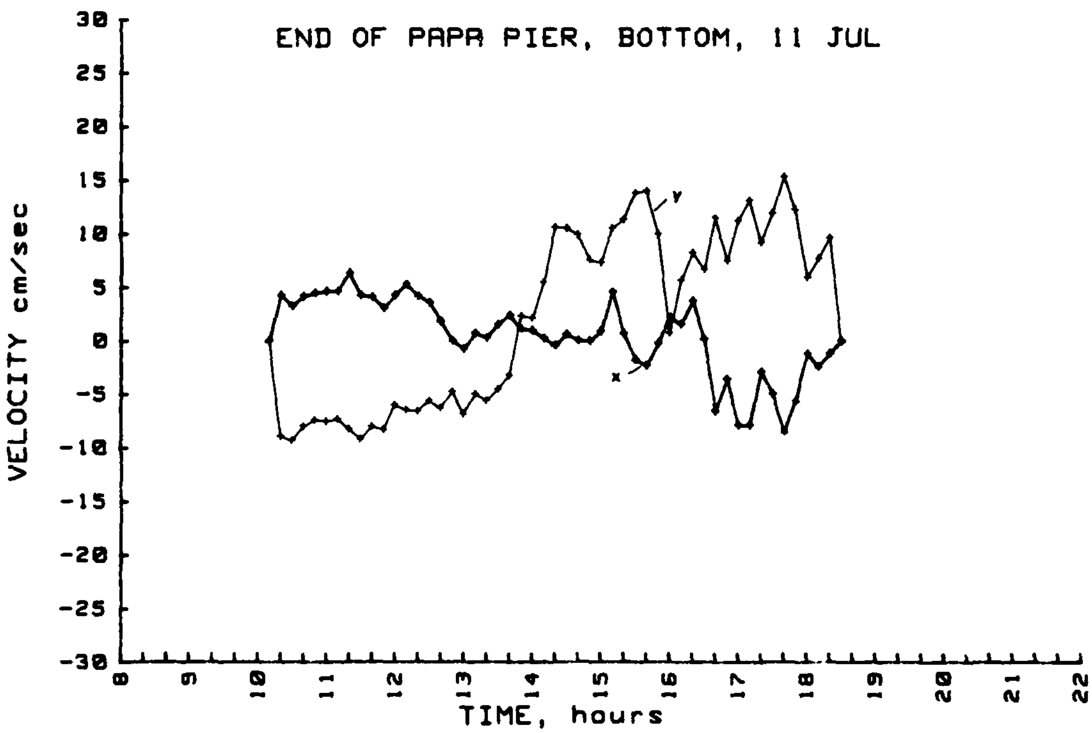

Figure 20. Measured parallel- (x) and cross-berth (y) bottom currents at the end of Papa Pier on 11 Jul 1984.

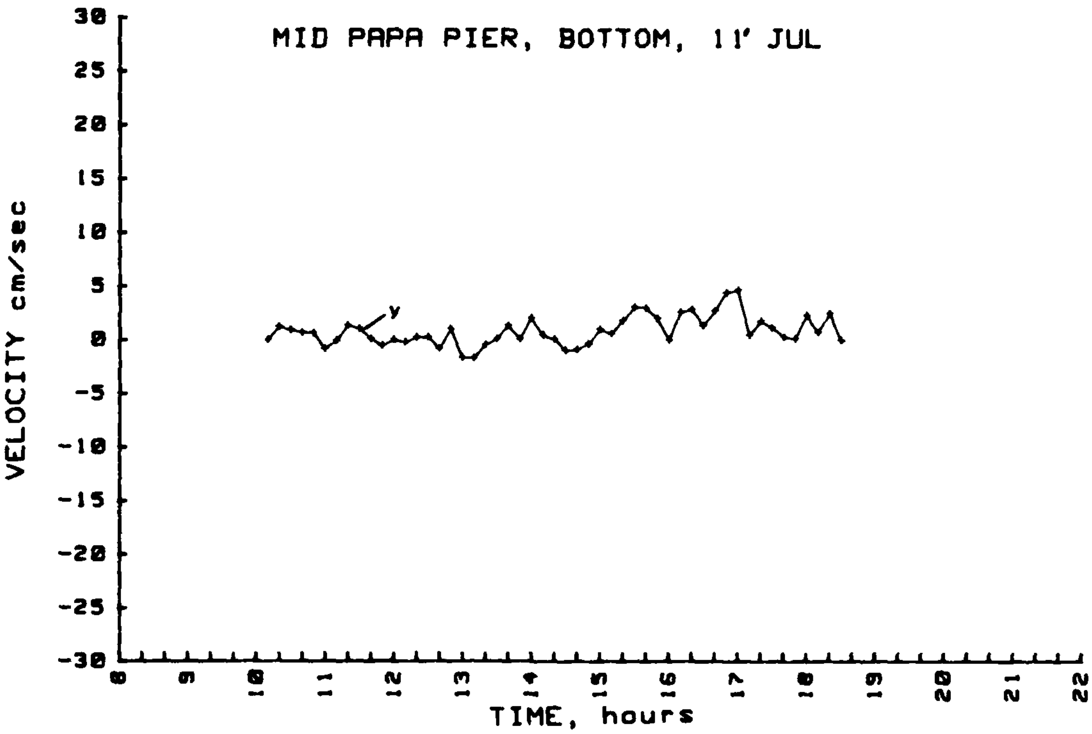

Figure 21. Measured cross-berth (y) bottom currents midway along Papa Pier on 11 Jul 1984.

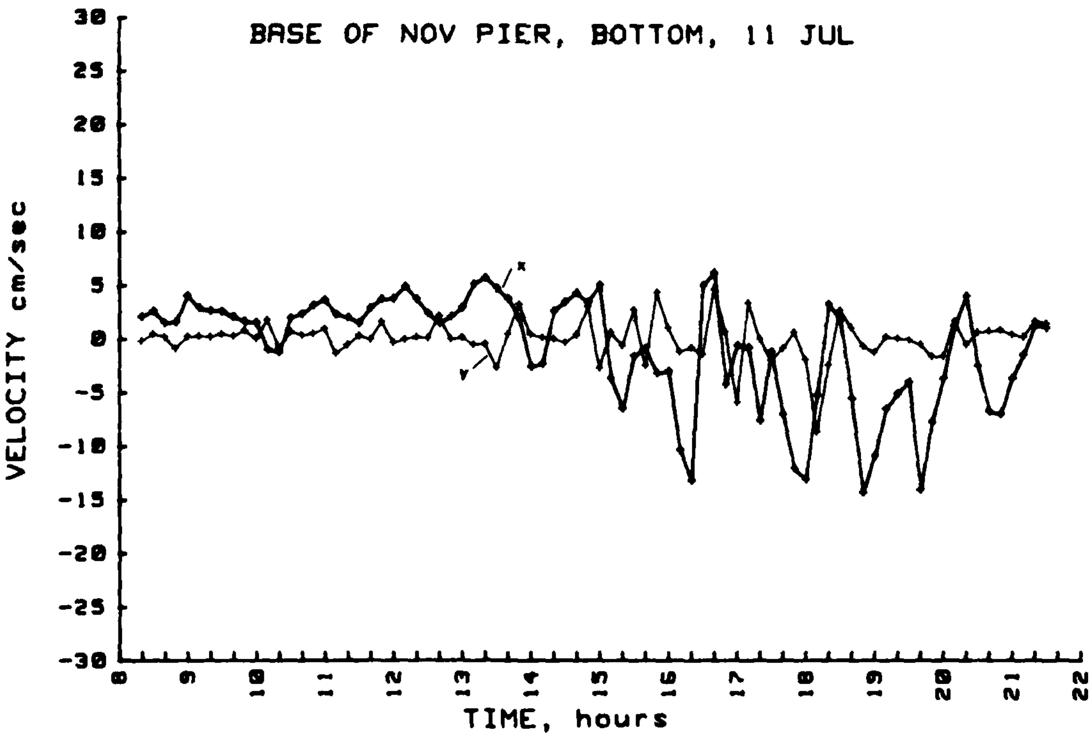

Figure 22. Measured parallel- (x) and cross-berth (y) bottom currents at the base of November Pier on 11 Jul 1984.

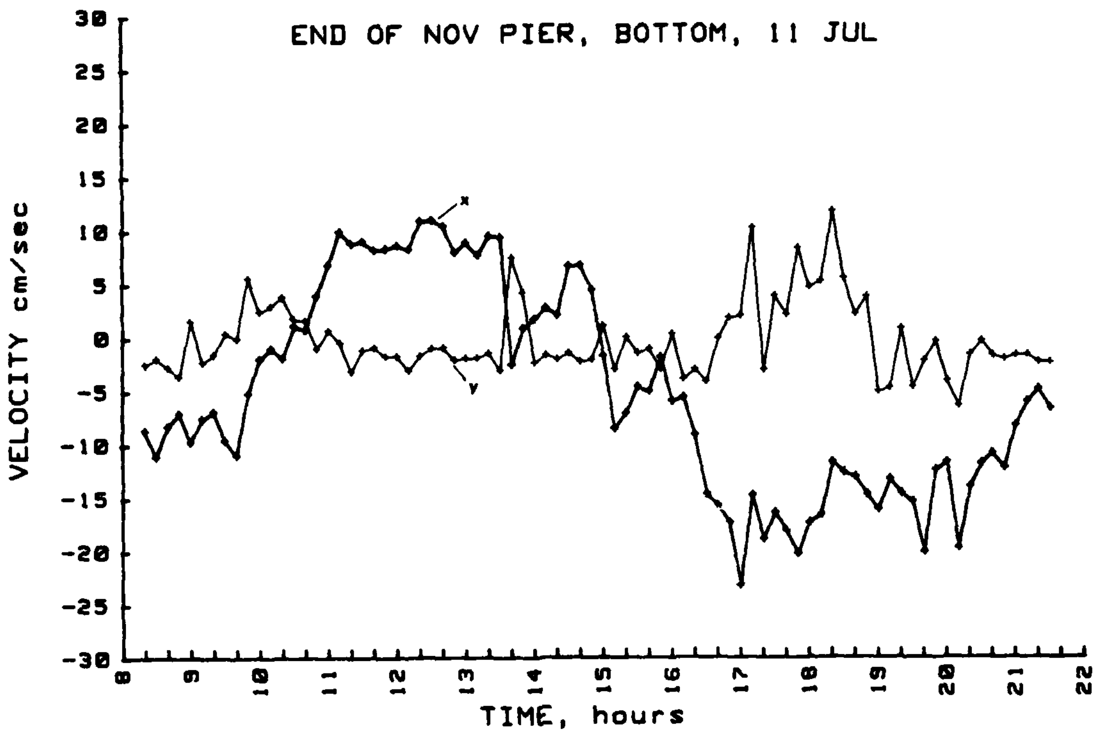

Figure 23. Measured parallel- (x) and cross-berth (y) bottom currents at the end of November Pier on 11 Jul 1984.

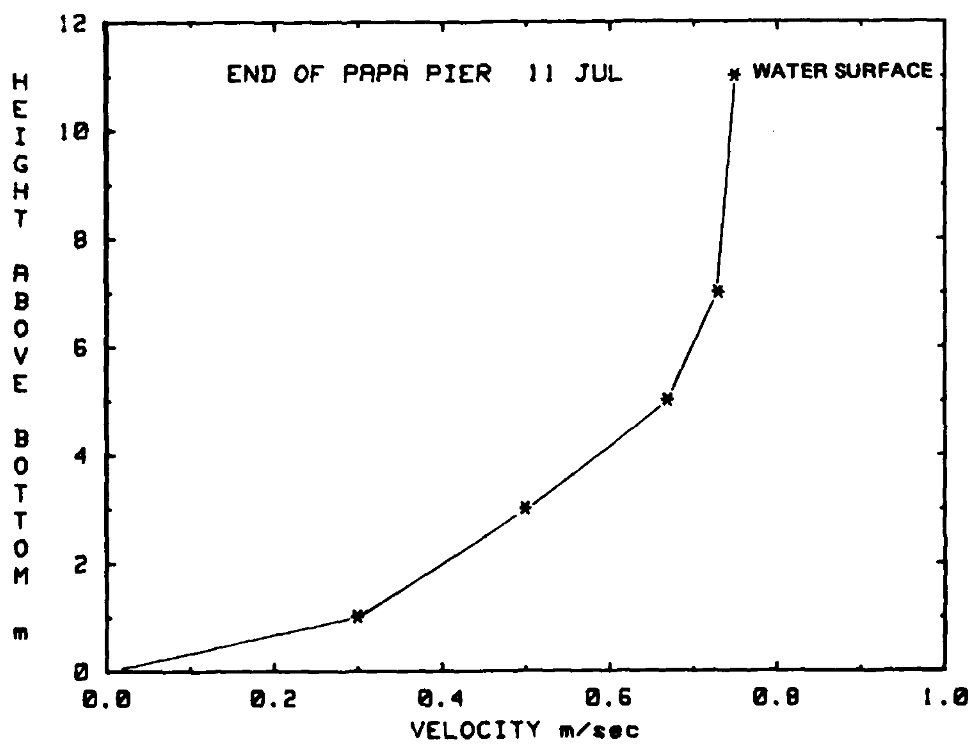

Figure 24. Vertical profile of velocity taken at the end of Papa Pier during maximum ebb flow. This profile is representative of undisturbed conditions in the river.

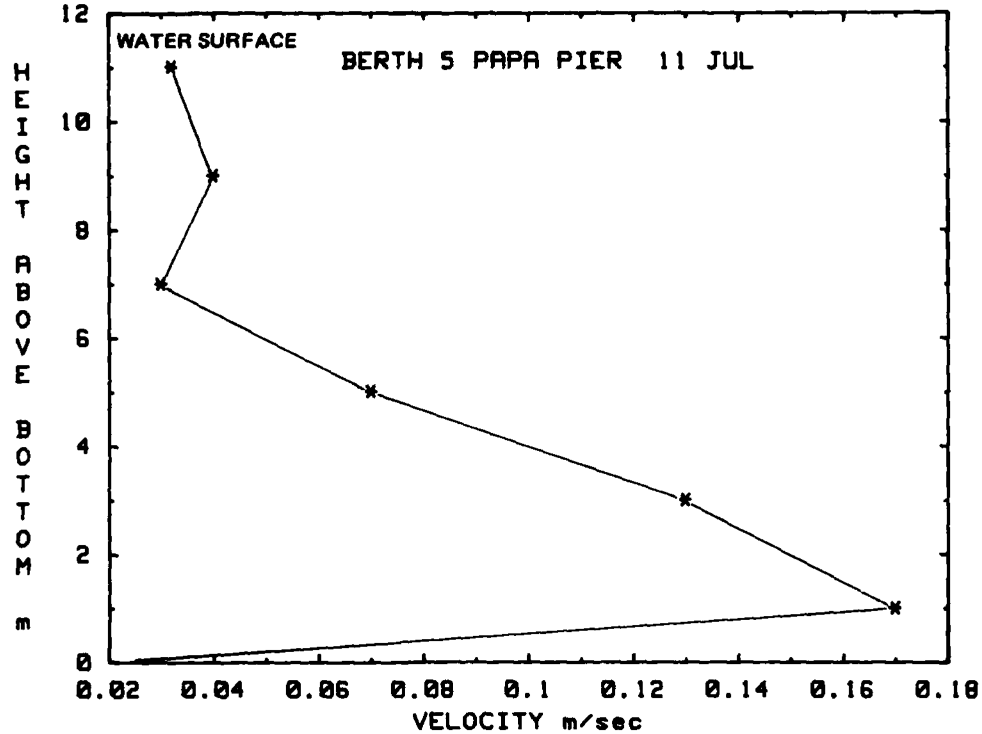

Figure 25. Vertical profile of velocity taken near the end of Papa Pier adjacent to a berthed ship. Note the blocking effect of the 5-m-deep ship.

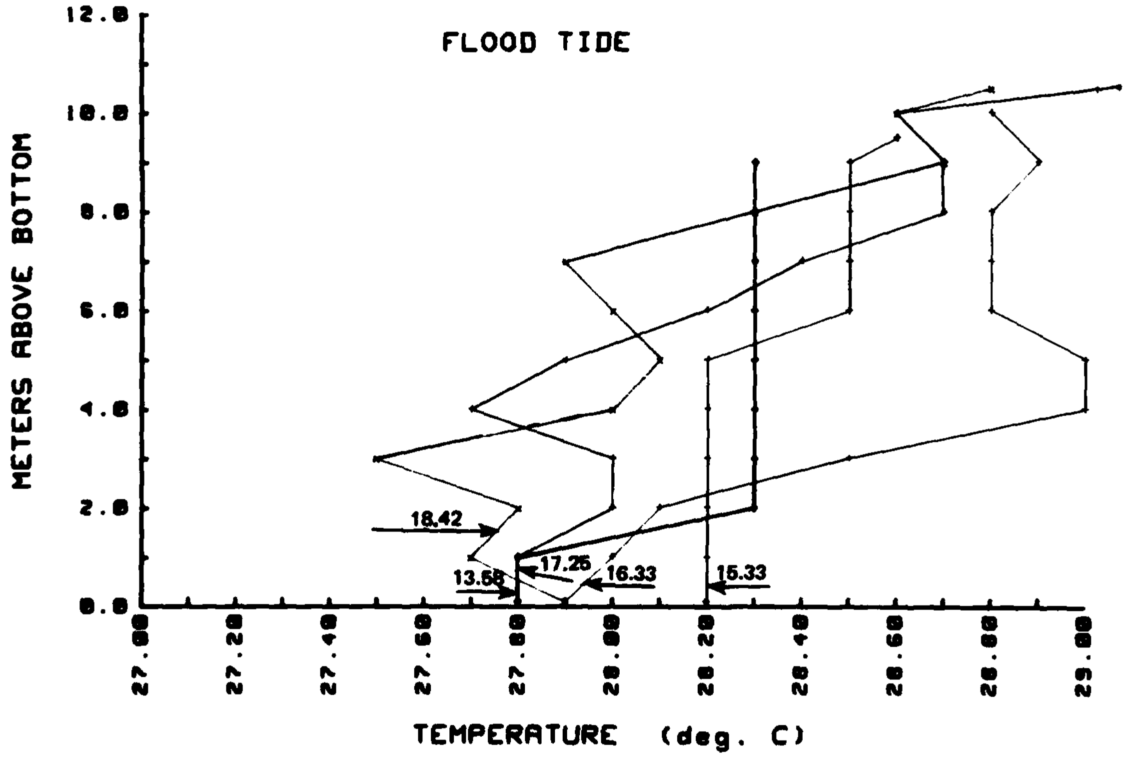

Figure 26. Vertical profiles of temperature taken during flood tidal flow on 11 Jul 1984.

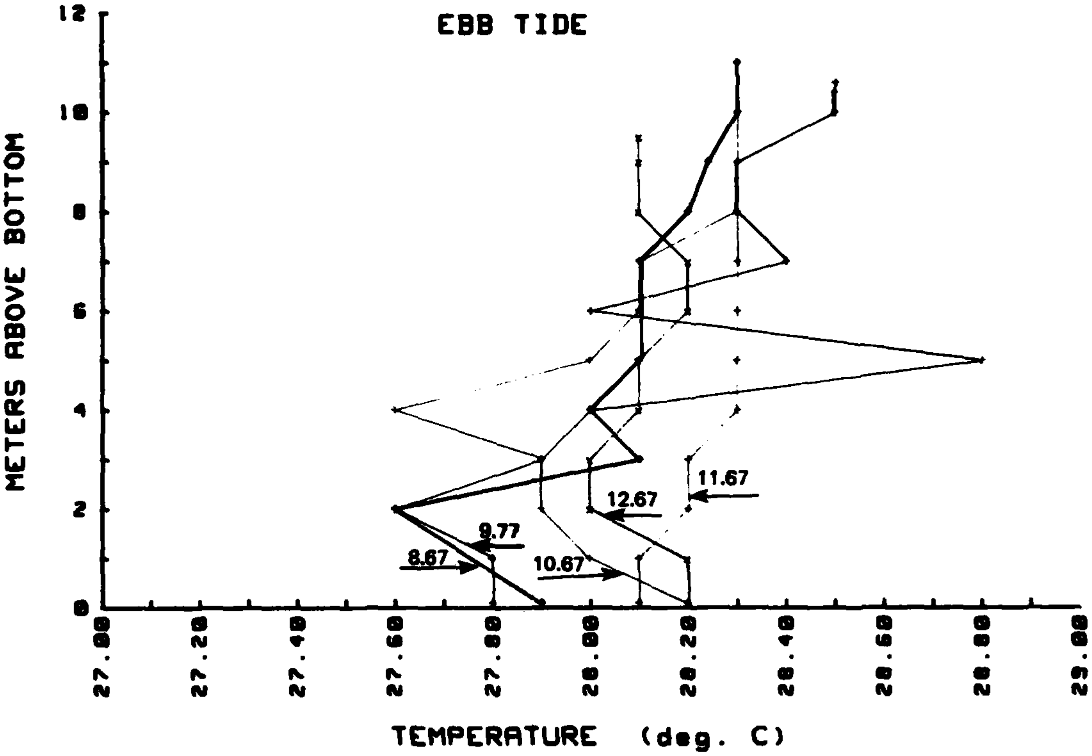

Figure 27. Vertical profiles of temperature taken during ebb tidal flow on 11 Jul 1984.

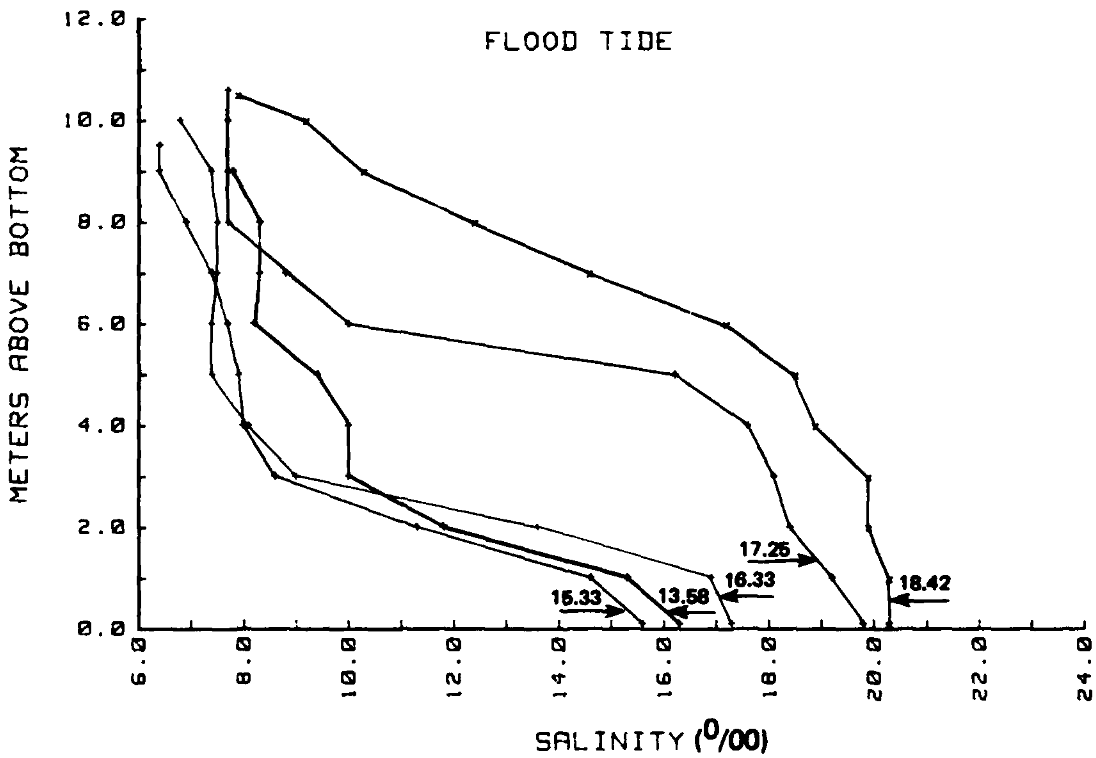

Figure 28. Vertical profiles of salinity taken during flood tidal flow on 11 Jul 1984.

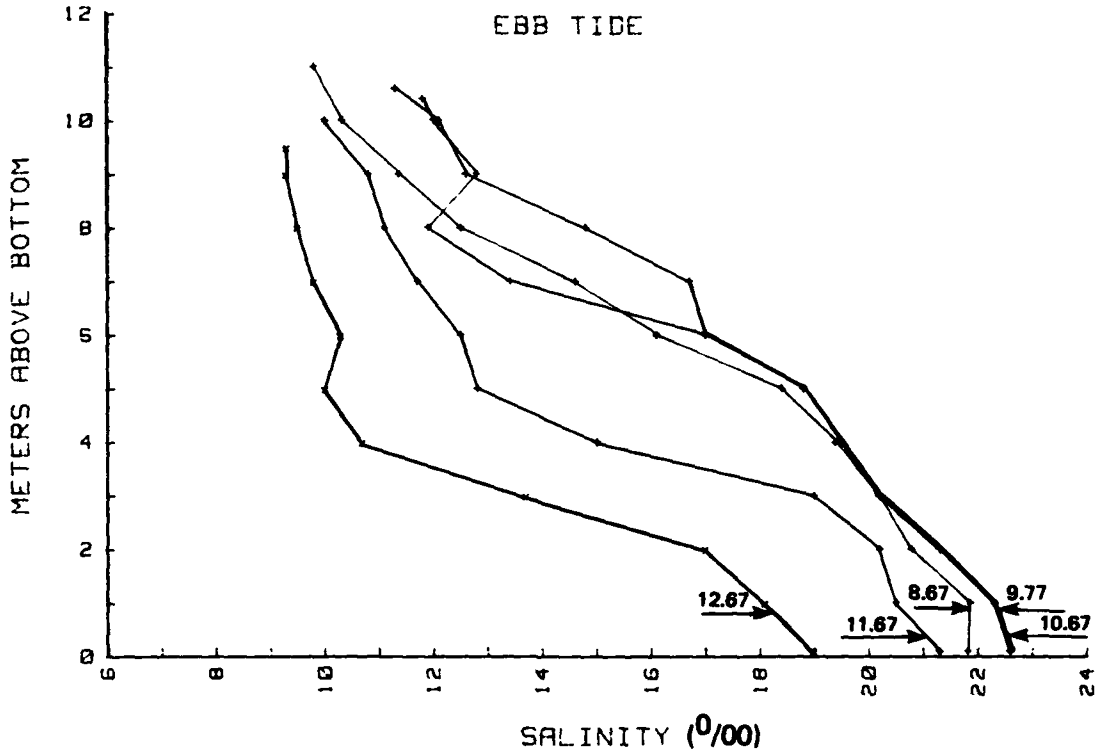

Figure 29. Vertical profiles of salinity taken during ebb tidal flow on 11 Jul 1984.

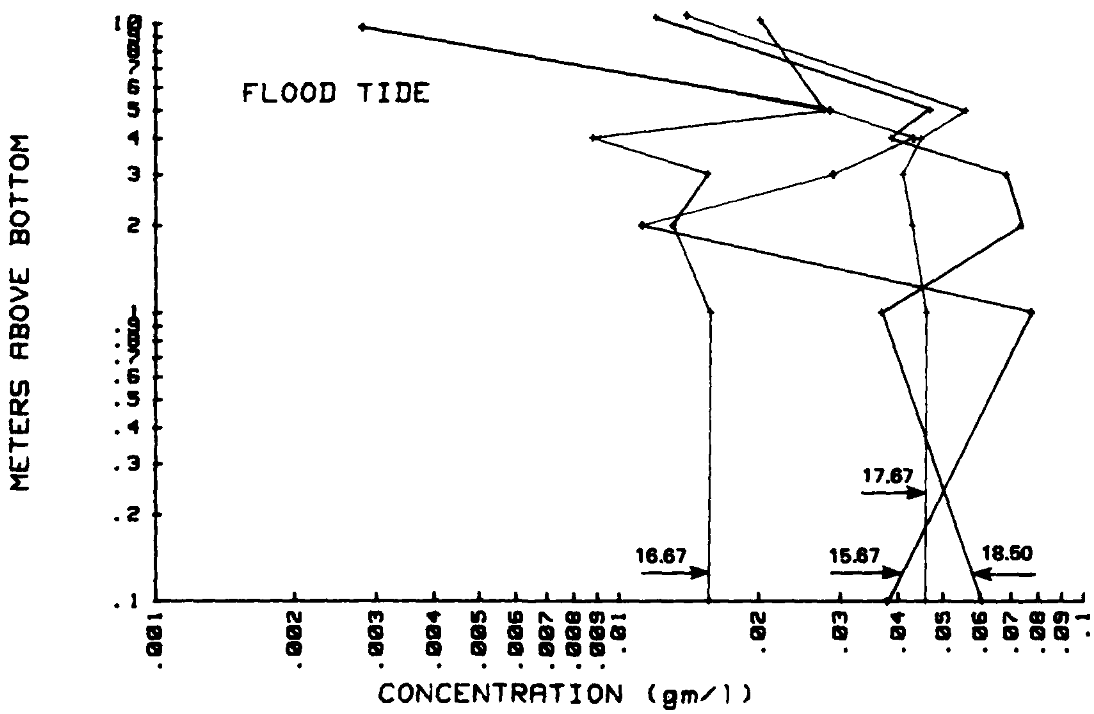

Figure 30. Vertical profiles of suspended sediment concentration taken during flood tidal flow on 11 Jul 1984.

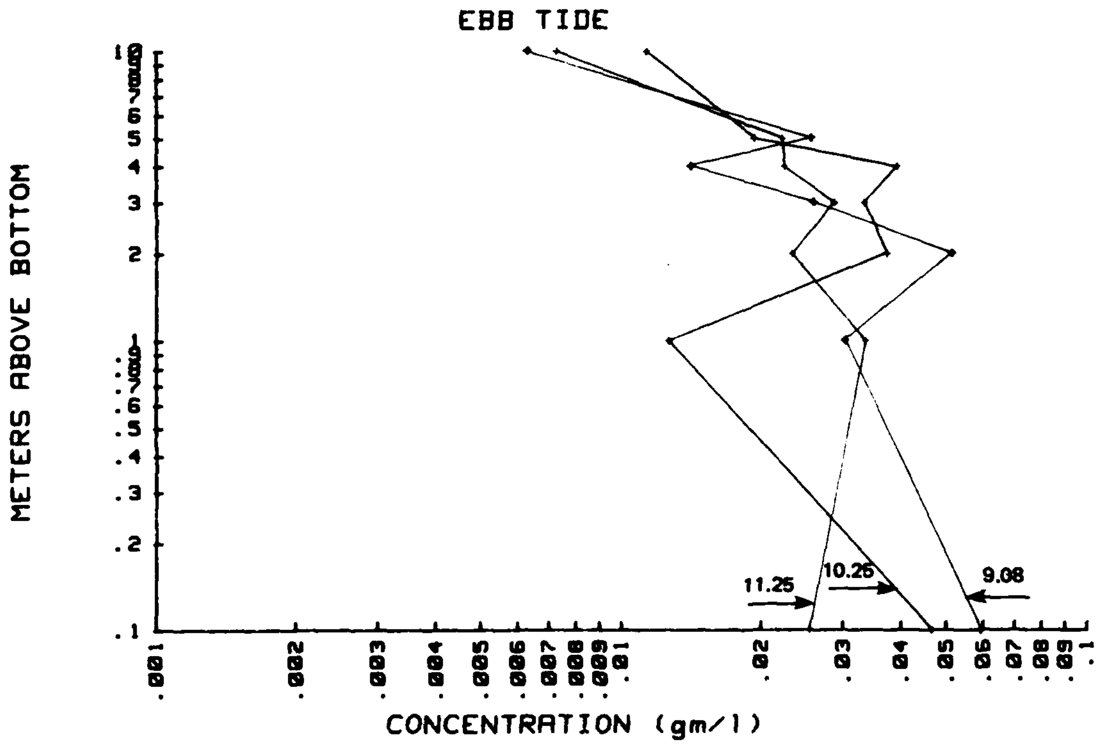

Figure 31. Vertical profiles of suspended sediment concentration taken during ebb tidal flow on 11 Jul 1984.

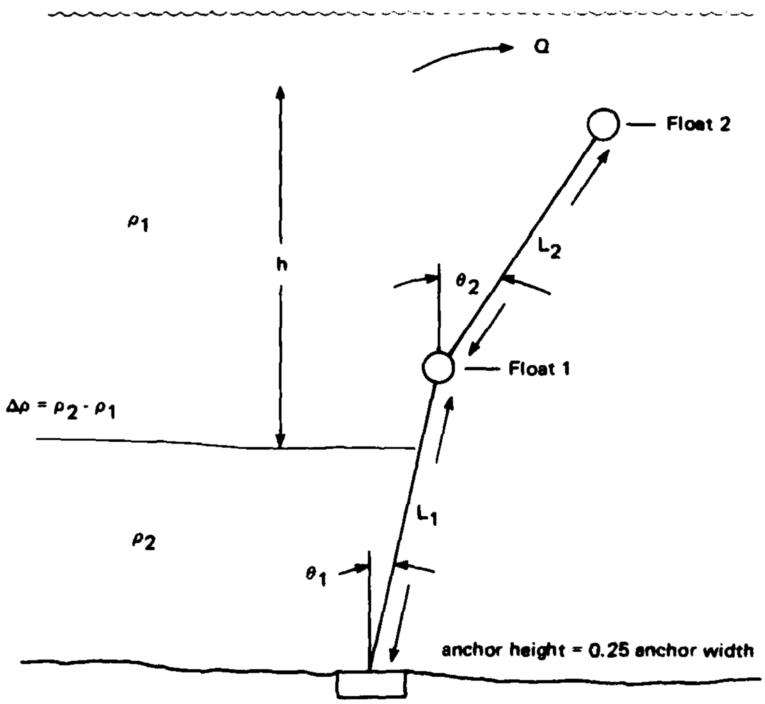

Figure 32. Schematic diagram showing curtain cross section and relevant parameters.

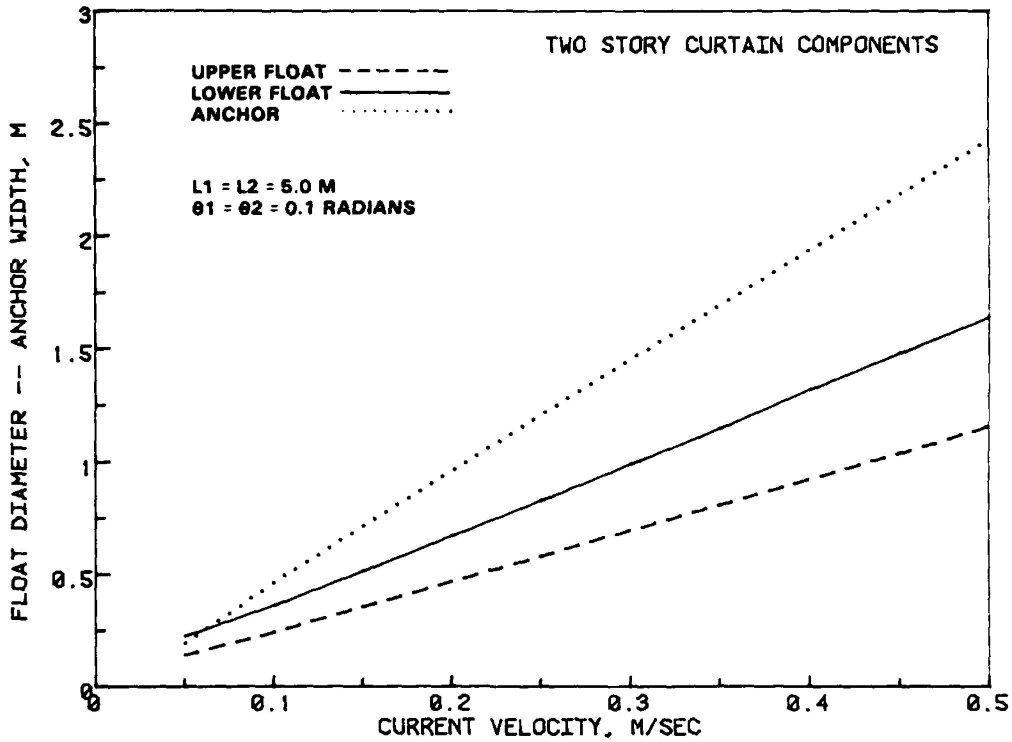

Figure 33. Curtain float diameter and anchor width as a function of the incident current magnitude.

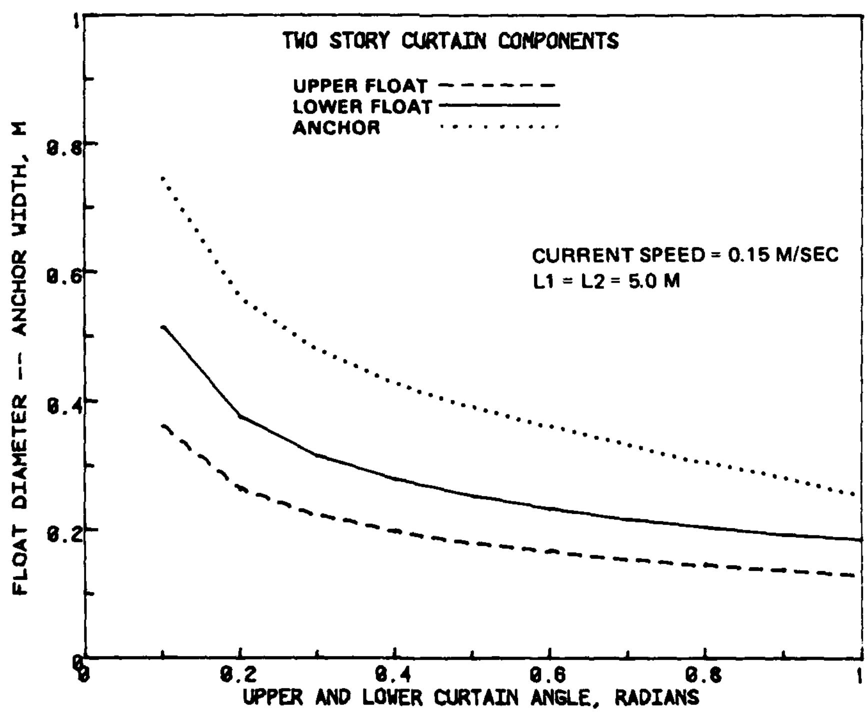

Figure 34. Curtain float diameter and anchor width as a function of the curtain response angle (upper and lower sections have the same angle).

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